A MANUAL

OF

METALLURGY.

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VOL. I.

FUEL, IRON, STEEL, TIN, ANTIMONY, ARSENIC,
BISMUTH AND PLATINUM.

ILLUSTRATED BY 59 ENGRAVINGS.

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PREFACE.

THE present volume is based largely upon the metallurgical syllabus issued by the Science and Art Department, and is primarily d signed for the use of students preparing for the advanced stage of those examinations. Yet it has been the endeavour of the author to present to the student a condensed and succint account of the *theory* and practice involved in the varied operations, comprised in the metallurgy of those metals which are of general application to the arts and manufactures; and, while sensible of the defects of the work, he ventures to hope, that to the general student of metallurgical or engineering science, and also to those practically engaged or interested in the conduct of the numerous processes comprised under its title, it may prove to be a *useful auxiliary* to, and *résumé* of, the contents of the more voluminous, exhaustive, and expensive treatises upon the various divisions of the subject.

Much of the work must necessarily be of a descriptive character, compiled largely from the larger modern treatises and papers; and of the numerous works to which it has thus been necessary to refer, the author takes this opportunity to acknowledge his obligations especially to the very excellent, comprehensive, and exhaustive treatises of Dr. Percy, and to the author's metallurgical notes made while a student in the same gentleman's classes and laboratories at the Royal

School of Mines.   Amongst other works that I have perused
with advantage, may be noted Bruno Kerl's *Handbuch der
Metallurgischen;* Truran's *Iron Manufacture of Great Britain;*
Lowthian Bell's *Chemical Phenomena of the Blast Furnace;*
various papers in the *Transactions of the Royal Society,* of
the *British Association,* of the *Institution of Civil Engineers,*
of the *Institution of Mechanical Engineers,* the *Journal* of the
Iron and Steel Institute, and in the pages of *Engineering.*

Throughout this volume the more modern but now almost
universally adopted chemical notation, nomenclature, and
atomic weights, have been adopted; but in many instances
where the same body receives two or more distinct names,
according to the nomenclature employed, the chemical symbol
of the substance has been added, in order to facilitate its
identification with the same body described under a different
name in treatises adopting the old nomenclature; and, in
exceptional cases, with the same object, decompositions have
been represented in the two notations.

The second and concluding part, embracing the metallurgy
of copper, lead, zinc, silver, gold, mercury, nickel, cobalt, and
aluminum, it is hoped will be issued early in this year.

W. H. G.

MANCHESTER, *January, 1874.*

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CHAPTER I.

INTRODUCTION.

METALLURGY.—"The art of extracting metals from their ores, and adapting them to the various purposes of manufacture."—*Percy.*

Metallurgy thus embraces a large cycle of operations of a chemical, physical, and mechanical nature; but it is with that division essentially chemical that the science of metallurgy chiefly deals, and which will form, to a great extent, the subject of the present volume—the operations of a purely physical or mechanical character being omitted or treated as briefly as possible. Thus the series of mechanical operations involved in dressing the ores, etc., belonging to the province of the miner, will not be further alluded to.

1. Metal.—This term was originally applied to all bodies possessing certain well defined physical characters, especially their *lustre and high specific gravity;* but at the present time the word must be taken in a more strictly chemical sense, since many bodies now considered non-metallic, as, for example, iodine, silicon, and selenium, possess many of those physical qualities formerly looked upon as the essential and peculiar qualities of the metallic state; accordingly about 50 of the *elementary* substances are classed as metals, though fresh discoveries continue to add to this number; and of these only about 15 are of sufficient importance in the arts to call for notice in the present work, viz., Aluminum, Antimony, Arsenic, Bismuth, Cobalt, Copper, Gold, Iron, Lead, Mercury, Nickel, Platinum, Silver, Tin, and Zinc.

2. Physical Qualities of the Metals.—Mercury is the only metal which, at the ordinary temperature of the atmosphere, exists in the liquid state. All others are *solid,* and all are *opaque,* except perhaps gold, which in an extreme state of tenuity transmits a greenish light; they reflect light from their polished surfaces, giving them a characteristic lustre known as the *metallic lustre.* The metals *silver, tin, cadmium, mercury, antimony, zinc, lead, bismuth,* etc., are *white* or *inclining* to white with bluish or yellowish tinges; *gold* stands alone as a simple metal having a *yellow* colour, and *copper* is the only *red* metal. The *specific gravity* of the metals ranges between ·58 (lithium) and 21·53 (platinum); the more *common* metals are, however, characterised by a *high specific gravity.* They differ widely in their behaviour under the influence of heat: thus some, as *tin* and *lead,* are fusible *below* redness; *copper, gold, silver,* etc., are readily fusible in ordinary furnaces; while *nickel, cobalt, manganese, iron,* etc., can only be fused with great difficulty; and *platinum, chromium,* and others are practically infusible; others again, as *arsenic, cadmium, zinc,* and *mercury,* are volatile, the former assuming directly the *gaseous* form without passing through the liquid state. The *brittle* metals may usually be obtained in well defined crystalline forms; to this class belong bismuth, antimony, zinc, etc. The *fracture* of the metals is often characteristic, and described as *crystalline, granular, fibrous, silky, columnar,* or *conchoidal;* of the first three forms mentioned, good specimens are afforded by the varieties of *iron* occurring in commerce, the *manganiferous* pig-iron known as *speigeleisen* being *largely* crystalline, *grey foundry pig* is *granular,* and ordinary *bar iron* is distinctly *fibrous,* the fracture of this latter, however, varying with the manner of breaking; *copper* affords an example of the *silky* fracture, and *tin* dropped in a fused state from a height becomes *columnar.*

3. Malleability, or "the property of permanently extending in all directions without rupture by pressure or hammering," is possessed in varying degrees by the metals; from such as bismuth, arsenic, etc., which are characterised as brittle or void of malleability, to gold and platinum, which may be laminated into leaves of extreme thinness;

some metals, though malleable to a considerable degree, require to undergo the intermediate operation of *annealing*, *i.e.*, heating to dull redness, and then allowing to cool down slowly, this being repeated once or more during the operation of hammering or rolling out; an example of such is furnished in the case of copper. The following are in order of malleability :—Gold, silver, copper, tin, platinum, lead, zinc, iron, nickél.

4. **Ductility,** or "the property of being permanently elongated by a tensile force, or of being drawn into wire," is possessed to a greater or less degree by all malleable metals, though the most malleable are not necessarily the most ductile, the ductility of a metal being more powerfully influenced by its tenacity than is its malleability. The following is the order of ductility :—Gold, silver, platinum, iron, copper, aluminum, zinc, tin, lead.

5. **Elasticity.**—The elasticity of a metal is the extent to which it may be elongated by tension without remaining permanently extended on the removal of the strain or stretching force.

6. **Tenacity,** or "the property of resisting fracture from a tensile or stretching force," is found to vary with the purity, the molecular condition of the metal as due to its mode of treatment or preparation, and with the temperature, the tenacity usually diminishing with an increase in the temperature ; the tensile strength of a metal is also generally decreased after heating to, or above redness, and then allowing it to cool without further treatment, due probably to the production of a more or less crystalline structure in the metal ; and often the presence of only traces of foreign metals, as for instance traces of lead, tin, and antimony in fine gold are sufficient to render that highly ductile metal quite brittle and weak under the action of a tensile force.

Before Fracture.   Fig. 1.   *After Fracture.*

The following are arranged in the order of their tenacity :— Steel, iron, copper, platinum, silver, gold, zinc, tin, lead.

Fig. 1 is one form of the test-piece employed in determining the tensile strength of the metals.

7. Conductivity.—The metals, with few exceptions, rank as the best conductors of both heat and electricity. Silver, gold, copper, zinc, iron, tin, platinum, lead, antimony, and bismuth, are in the order of their conducting power for heat, while in conductivity for electricity they stand as follows: viz., copper, gold, zinc, platinum, iron, nickel, tin, lead, antimony, and then bismuth.

8. Welding.—Certain of the metals possess the peculiar property termed *welding*, whereby, if two clean surfaces be brought into contact and pressure applied, the two adhere together, and become part of one and the same mass; this quality is signally possessed by iron at a white heat; and lead or gold in a fine state of division, if pressed together strongly at the ordinary temperature, adhere, forming one mass.

9. Toughness.—Toughness, as applied to the metals, is the property of resisting fracture by bending or rolling.

10. Softness.—Softness, or the property of easily permanently yielding to pressure without fracture, or as being easily sectile, is typically marked in the case of lead.

The hardness of metals is usually estimated by the resistance offered or force required to draw wires of equal diameter, and of the same temperature, through a hole of a given size; thus, steel, iron, copper, silver, tin, antimony, and lead, are in order of hardness.

CHAPTER II.

METALLURGICAL TERMS.

11. Ore, etc.—"*Ore* is the name applied to the metalliferous matter in the state in which it is extracted from the earth by the miner."

The *ore* is usually an oxide, sulphide, carbonate, chloride, phosphate, silicate, or arsenide of the metal, or various mixtures of these, mixed with extraneous matter, often earthy or stony, as quartz, felspar, hornblende, various silicates, carbonates of lime, magnesia, etc., heavy spar or barytes, fluorides, etc., as well as portions of the rock adjoining the mineral lode ; this extraneous matter is designated *vein-stuff*, *matrix*, *or gangue*.

12. Native Metals—When the metal occurs uncombined with any other chemical element or elements, it is said to occur *native ;* of such occurrences gold and platinum afford examples, though these are always accompanied by silver in small quantities.

13. Dressing Ores.—The mechanical operations necessary to prepare the material extracted from the mine for the smelting processes, are known as *dressing* operations, and consist in *breaking* the ore, *sorting*, and *washing;* operations performed with varying degrees of care, according to the value of the metal to be extracted, and to the future requirements of the smelting operations ; for, as will hereafter be shown, certain proportions of *gangue* or stony matter may be useful for the subsequent separation of the metal in the furnace, by forming under the furnace conditions a fusible slag with the other extraneous matters of the ore, from which the reduced metal readily separates in virtue of its superior specific gravity.

14. Reduction.—Reduction is the process of separating

the metal from its ores, or from its chemical combination. The substance effecting this separation or reduction is known as the *reducing agent*. The noble metals, gold, silver, platinum, mercury, etc., are reducible from their oxides by the application of *heat* alone, which thus becomes the reducing agent.

15. Smelting.—This is the "name applied to the process or series of processes whereby a metal or metallic compound is separated by fusion from its ore."

16. Flux and Slag.—Flux is the name given to the substances added to the furnace charge of ore and reducing agent, for the purpose of combining with the extraneous matters of the charge, and forming therewith a fusible compound designated *slag*, through which the metallic particles, in virtue of their superior specific gravity, readily sink and collect beneath the layer of fused slag on the surface.

17. Regulus, Matt, and Speise.—In smelting certain metallic sulphides, instead of obtaining, as above, merely *metal* and *slag*, it is frequently desirable, before finally extracting the metal, to concentrate the metallic matter in a fusible mass of mixed sulphides, designated as a *regulus* or *matt*, which regulus is then the object of a subsequent operation for the extraction of the metal. Similarly, if *arsenical* ores, as ores of nickel and cobalt, be the subject of treatment, a compound occurs similar to the above, but containing arsenic instead of sulphur, which is then called speise ; and in certain operations *slag, regulus, speise,* and *metal* may all be obtained as products of the *same* operation, occurring in layers in this order on the bed of the furnace.

18. Roasting.—The operation of roasting may have for its object the expulsion of water, carbonic acid, etc., to volatilize or sublime certain volatile compounds, or to oxidize the ore or metallurgical product. Roasting is conducted either in large heaps in the open air, or by placing the ore on the bed of a reverberatory furnace ; in the former case, the ore is mixed with fuel, then ignited and allowed to burn itself out ; while in the latter method, the ore does not come in contact with the fuel, which is burnt on a separate grate ; in either case, the object is to heat the ore at a comparatively low temperature with free access of air

19. Liquation.—Liquation is the term applied to the operation of separating two or more metals whose fusibilities differ, by heating the mixture to a temperature sufficient to melt the more fusible metal only, which then flows from the alloy or mixture of metals, leaving the less fusible substance on the bed of the furnace or other liquating apparatus.

20. Slags.—The slags occurring in metallurgical furnaces, with only few exceptions, as in smelting lead ores, are *anhydrous silicates*, the most frequent being silicates of lime, magnesia, alumina, iron, and manganese, with small quantities of potash. Dr. Percy gives an analysis of a blast furnace slag, from which he deduces the formula—

$$R_2O_3, SiO_3 + 2(3RO, SiO_3)$$
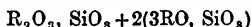
which on converting into the modern formula where silica is represented as SiO_2, becomes

$$2R_2O_3, 3SiO_2 + 6(2RO, SiO_2).$$
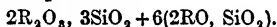
R is any metal. The same author represents the slag from the refining furnace as

$$3FeO, SiO_3,$$

or transforming becomes

$$2FeO, SiO_2.$$
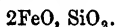
The slags produced in smelting operations are generally *grey, blue, green, brown, red, or black* in colour, often presenting a *veined* or *marbled* aspect; they are either glassy or dull and opaque, according to the rate at which they have been cooled; if cooled quickly the slag may be brittle and glassy in appearance, while if cooled slowly it will be dull, opaque, and often very tough. The colour of the slag is due to the presence of metallic oxides.

21. Clays.—Clays are essentially *hydrated* silicates of alumina, with varying amounts of iron, lime, magnesia, potash, etc., along with more or less mechanically mixed silica; but the proportions of silica and alumina present in clays apparently the same, and coming from the same locality, are found to differ widely. Clays owe their plastic quality to their chemically combined water. Clays which will withstand exposure to a high temperature without melting or sensibly softening are described as *fire-clays;* such occur largely in the carboniferous, and more sparingly in other geological

formations. The fire-clay employed for the manufacture of *crucibles* or *fire-bricks*, should contain only a very small proportion of alkali, and be free from iron pyrites (FeS_2).

22. Crucibles.—"This term is usually applied to such open mouthed movable vessels, in which bodies are exposed to high temperatures, as are movable by tongs."

Good crucibles should be capable of resisting a high temperature without sensibly softening, should not be tender while hot, ought to stand sudden and great alternations of temperature without cracking, and resist the corrosive action of materials such as litharge, etc., and the action of the fuel.

Crucibles are made of mixtures of fire-clays, burnt clay, silica (sand), graphite, coke-dust, and ashes; the burnt clay being usually the old pots (crucibles) freed from adhering slag, broken and ground up, its admixture assisting in the prevention of the cracking of the crucibles on drying, which occurs if raw clays only be used. Mixtures of clays are preferred for making crucibles: thus, for the crucibles used in the melting of steel, a common mixture consists of Stourbridge-clay, china-clay, blue-clay, ground pots, and coke dust; the ingredients are ground fine, so as to procure uniformity in the size of the particles, then mixed on the floor, water thrown over it, and the mass kneaded by the workmen treading it barefooted for several hours, the clay being turned over with the spade at intervals; the mass is then cut up and weighed into portions called *balls*, each sufficient for one pot (crucible); each *ball* is worked by hand on the table or bench before being finally moulded into form, an operation performed either by a machine or in a mould by hand. The crucibles are now transferred to shelves around the steel-house, where they remain about a fortnight before using, so as to be thoroughly dried; and before their final use for melting purposes, are annealed for from 15 to 18 hours in a separate furnace, from which they are removed while still hot and inserted in the melting furnace. These pots hold about 50 lbs. of bar-iron cut into small pieces.

The small crucibles used by assayers, etc., are kiln-burnt.

Plumbago crucibles contain only so much clay as will suffice to give the mixture of clay and plumbago the necessary plasticity; the plumbago is hand-picked, ground, and sifted

before mixing with the clay. These crucibles withstand a higher temperature without softening than do the clay crucibles, also greater alternations of temperature without cracking; their surface is also smoother, and particles of metal do not cling to their sides.

Cornish, London, and *Hessian* crucibles are smaller crucibles used by assayers, differing only in shape, and made from mixtures of fire-clay and sand. Accompanying are sketches of London, Cornish, and steel melting crucibles.
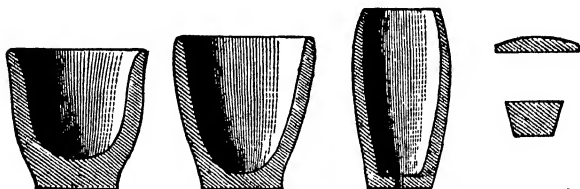
Cornish Crucible. London Crucible.   Crucible, Cover, and Stand

Scale, ⅕.   employed for melting cast-steel—*Scale,* 1⁄10.

Fig. 2.—CRUCIBLES.

For making certain assays, as, for instance, the dry assay of an iron-ore, it is necessary to have a crucible with a carbonaceous lining, or, as it is technically called, a *brasqued* crucible. This *brasque* may be made either of wood-charcoal and starch, of gas-carbon mixed with coal-tar, or, for the small iron assay crucibles, a good lining may be made by a mixture of ground charcoal and treacle; the inside of the clay crucible is lined with this mixture, pressed moderately hard, and the crucibles, covered over to prevent the ready access of air to the lining, are heated to redness; when gases cease to escape from the decomposition of the treacle, the crucibles can be taken from the muffle or furnace, and when cold are ready for use.

23. Fire-Bricks.—The qualities already stated as required to constitute a good crucible, apply also to the case of *fire-bricks.* In the manufacture of fire-brick, the fire-clay is ground between rolls or under-edge stones, kneaded with

water, and moulded like ordinary bricks, then thoroughly dried and baked in closed kilns. They must always be set in a mortar of fire-clay, and not in the usual lime mortar, otherwise, at the intense heat to which they may be subjected, chemical union would occur between the free mechanically mixed silica of the clay and the lime, with the production of a fusible silicate, and consequent rapid destruction of the structure.

24. Dinas Brick.—This is an exceeding'y refractory brick used for the roof of reverberatory furnaces, etc.; it presents a rough hackly appearance or fracture from the presence of fragments of white quartz embedded in a yellow matrix. The material of these bricks occurs in the Vale of Neath, and contains about 97 per cent. of silica, the remainder being alumina, oxide of iron, lime, alkali, and water. The bricks are made by mixing the ground or crushed clay with from 1 to 3 per cent. of lime. The mass is then moistened with water and pressed into iron moulds of the form required; they are then carefully dried and heated in kilns for about seven days.

25. Annealing Furnace.—The annealing furnace used for the annealing of the large crucibles used in steel melting, is a rectangular chamber of brick-work (see fig. 42), the fire-bars placed close together form the bed; the front of the furnace is closed by an iron door z, which moves vertically upwards and downwards, while the interior communicates with the atmosphere by a small flue or stack at its summit; a layer of fire to the depth of a few inches being made over the whole surface of the bars, which is covered with small cinders or coke, the pots are then packed in mouth downwards, the whole being then covered with small coke, the front is closed, and the whole left for from 12 to 20 hours, when the pots will be thoroughly dry, at a red heat, and ready for insertion into the melting furnace.

CHAPTER III.

FUEL.

THIS term is applied to all those materials which are practically employed for the generation of heat.

The fuels used in all metallurgical operations, *i.e.*, *anthracite, bituminous, caking, cannel,* or other kinds of *coal, peat, lignite,* and *wood,* or their derivatives, as *coke, charcoal,* etc., are all of *vegetable* origin. The elementary constitution of the fuels will accordingly be much the same, though the relative proportions of the elements differ widely; these elementary constituents are *carbon, hydrogen, oxygen, nitrogen,* and *inorganic* or *earthy* matter, the latter constituting the *ash* of the fuel; the amount of this latter varying from 1 per cent. to 4 per cent. in wood, and from 1 per cent. to 20 per cent. in the denser fuels.

26. Wood.—Wood cannot be used as the fuel where high temperatures are required, owing to the large amount of water it retains, unless it has been previously kiln-dried; timber which has been felled and exposed to the atmosphere for a considerable time, so as to become thoroughly air-dried, still retains about 20 per cent. of water. Hence, for metallurgical operations, the wood to be available as a fuel must first be converted either into charcoal, or subjected to dessication or drying at a temperature which is almost sufficient to char the wood.

The woods most commonly employed as fuels are sycamore, birch, deal, ash, elm, oak, fir, larch, etc. The earthy matter or ash of this class of fuel contains potash, soda, lime, magnesia, a little oxide of iron, silica, phosphoric acid, sulphuric acid, and chlorine, but is marked by the absence of alumina.

27. Peat is the product of the slow decay without access

of air of various kinds of plants, in this country especially of the mosses; but like wood it retains water sufficient to render it unavailable for the production of high temperatures. Even after cutting into squares and piling so as to thoroughly air-dry it, peat still retains from 20 to 40 per cent. of water; this class of fuel also contains an excessive amount of inorganic matter, the ash frequently amounting to 10 or even 20 per cent. of its weight. The *ash* contains potash, soda, lime, magnesia, alumina, oxide of iron, phosphoric and sulphuric acids, chlorine, silica, and silicates; the lime in some cases amounting to 36 per cent., and the oxide of iron to 15 per cent. of the total weight of the ash. It is also noticeable that whereas the ash from peat contains *alumina* and *oxide of iron*, that from wood is void of *alumina*, and contains but a trace of *oxide of iron*.

28. Coal.—The different varieties of coal form by far the most important class of substances employed as fuel.

Coal is a solid mineral substance, more or less combustible, of a dark brown or black colour, opaque, except in very thin slices, brittle, infusible without decomposition, not sensibly soluble in ether, benzol, or solvents of resinous matters; the percentage of carbon is greater than that in peat or wood, and the proportion of oxygen to hydrogen in the fuels exists here at the minimum, the ratio increasing in the different varieties of fuel as they approach nearer to the characters of wood, in which the ratio has its maximum. For during the decomposition and solidification of the vegetable matter necessary for the formation of coal, gaseous products, as marsh gas (CH_4), the fire-damp of the miner, along with other hydrocarbons, carbonic acid (CO_2), etc., are emitted (either slowly and quietly, or, if accumulated under pressure, sometimes escaping with violence); and in this manner the oxygen and hydrogen of the original vegetable matter is more or less completely removed, according as the change from wood to coal is more or less complete, until, as in anthracite, *carbon* forms 90 per cent. of the entire mass.

Sulphur is always present in coals, either as sulphate of lime and iron pyrites, or in combination with the organic constituents of coal; *silica* and *alumina* also are invariable components of the ash of coal.

Coals are classed by Dr. Percy as—

1° *Lignites*, ... { Bituminous Wood.
                          { Brown Coal.
                          { Non-caking, rich in oxygen.
2° *Bituminous Coal*, . . { Caking.
                          { Non-caking, rich in carbon.
3° *Anthracite*.

The *lignites* are brown, brownish-black, or black in colour, with a dull or shining lustre, either wood-like, earthy, or compact in structure; they are non-caking, and differ from other varieties of coal in the large proportion of water, amounting to 15 or 20 per cent., which they retain after air-drying; oxide of iron, silica, and alumina form the chief ingredients of their ash.

Bituminous coals mostly burn with a more or less smoky flame; certain varieties of the class, when heated, swell up and become pasty, becoming eventually, if the heat be continued without the access of air, converted into a hard coherent mass termed *coke*, and are hence described as *caking* coals; other varieties, heated under the same conditions, either split up or retain their form without the particles cohering together, these latter are described as *non-caking* or *free-burning* coals.

The *bituminous* coals contain more hydrogen and oxygen than the anthracites, and thus stand between them and the lignites in chemical composition.

Anthracite has a stronger lustre than bituminous coal, and, as already mentioned, contains a much greater proportion of carbon than any other class of coal, this element forming 90 per cent. of the fuel; it contains very little volatilizable matter, and burns only with considerable difficulty, requiring a much stronger draught for its combustion than the other classes of coals, but in its combustion generates an intense local heat, and is hence much used in melting operations. It decrepitates and crumbles away when thrown upon a hot fire, and is non-caking.

Coals often contain a notable quantity of foreign minerals, as *sulphides, oxides*, etc., of copper, iron, arsenic, antimony, lead, etc.

29. Charcoal.—When wood is heated to about 300°C. out

of contact with the atmosphere, or with only a limited supply of air, it suffers decomposition; the more volatile products, as oils, tars, ammoniacal compounds, volatile hydrocarbons, etc., distil off and may be condensed; at the same time another portion of the oxygen, hydrogen, and carbon escape as carbonic acid, carbonic oxide, and carburetted hydrogen, along with hydrogen and other permanent gases, and there remains behind a more or less porous carbonaceous residue called *charcoal*, retaining the original form and structure of the wood, and which consists essentially of the carbon of the wood along with its fixed or inorganic constituents, as also a little oxygen and hydrogen from which it cannot be freed by heat. The charcoal is more or less compact according to the temperature at which the carbonization has been effected.

Charcoal is a bad conductor of heat and electricity, its conductivity being increased the higher the temperature at which it has been prepared. Its specific heat is ·2411; its specific gravity varies with the nature of the wood and mode of carbonization, but ranges between ·106 and ·203; when burnt, charcoal leaves from 1 to 5 per cent. of ash.

The yield of charcoal varies with the mode of preparation, heat, and rapidity of carbonization, as well as the nature of the wood operated upon, and varies accordingly from 50 per cent. to 75 per cent. by volume of the wood from which it is produced, or from 15 per cent. to 25 per cent. by weight. The yield is greater the lower the temperature of charring the wood, thus the average yield by rapid charring is 23 per cent., and only 14 per cent. if carbonized slowly.

The wood for charcoal burning should be of mature growth and felled during winter; rotten and worm-eaten wood is bad, and timber is deteriorated for charcoal burning if long soaked in water.

For blast-furnace or forge purposes the charcoal is better if kept for some months previous to using.

30. Mode of Preparation.—Charcoal burning is effected either in heaps, stacks, or piles in the open air, in pits, or in closed chambers of brick, stone, or iron, heated either by the combustion of the volatile products of the distillation of the wood itself, or from a separate source of heat

applied externally to the chamber, as by superheated steam, etc.

31. Charcoal Burning in Piles.—For this purpose a suitable piece of ground, level and sheltered from the wind, is selected, clayey ground being avoided. Three stakes are then driven vertically into the ground (see fig. 3), which are to form the chimney of the pile at the commencement of the operation, the billets of wood are then arranged in nearly vertical and concentrical rows around this chimney, the billets leaning slightly inwards so as to be self-supporting. The spaces between the billets are filled up by the smaller branches and twigs of the trees; two or three rows in vertical height
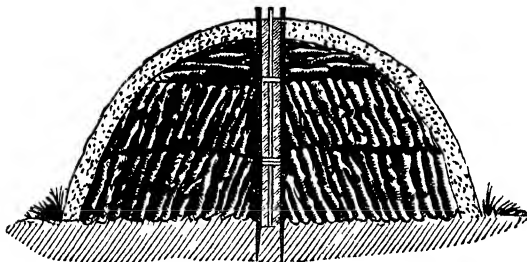
Fig. 3.—CIRCULAR PILE FOR CHARCOAL BURNING.

are thus built up, forming a large conical heap, the top being formed by a quantity of the smaller pieces of timber laid transversely, and so tying the pile together; the surface is now covered closely over at every part except the opening at the top (formed by the three stakes first mentioned), and a few openings around the base of the pile for the admission of air. The space between the three stakes previously cited is now filled with small and more easily inflammable twigs, which are ignited, the combustion rapidly extending to the wood in its vicinity; in the first or sweating stage much water appears in the covering and at the base of the pile; when this is over the cover is made tight, the combustion proceeding from the top to the bottom, and from the centre to the outside of the heap, vents being made at varying heights around the pile, commenceing at first near the top,

which are closed as carbonization in that region or zone is
supposed to be completed, judging by the smoke which issues
from the vents so made; the smoke at first is thick and
white, becoming, as the process approaches completion,
thinner and pale blue in colour, with occasionally a blue
flame appearing, the vents in this region are then closed, and
a series lower down in the pile made, and so on until the
whole pile is carbonized; as the process proceeds, any sink-
ings that may occur from the unequal burning of the wood
are filled up by removing the cover at the part and inserting
fresh wood. Combustion being completed, the pile is covered
with ashes, and left to cool for two or three days; it is then
taken to pieces, beginning at one side, the portions still hot
are quenched by throwing water or sand upon them.

In another method of burning, instead of the billets being
arranged in vertical rows around the centre, they are laid
horizontally around the central stakes or chimney (fig. 4).
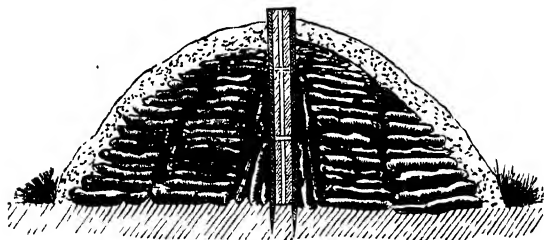
Fig. 4.

In other modes of charcoal burning in piles, the wood is
cut into lengths of about 8 feet, and these are laid transversely
on the ground so as to form a rectangular pile 24 feet long,
and increasing from a height of 2 feet at the lower end to 7
or 9 feet at the other; the sides of the pile are formed by
planks supported by props or stays; the space between the
wood to be burned and these planks, is rammed with
moistened "breeze" or small charcoal, the top of the pile
being covered with leaves and faggots (see fig. 5). The pile is
lighted at the lower end, and as the process proceeds holes
are opened and closed at different points, as described for the

previous method, commencing at the lower end and proceeding towards the higher, until when the higher end is in active operation, the lower end will have ceased to burn, and be cooling down.
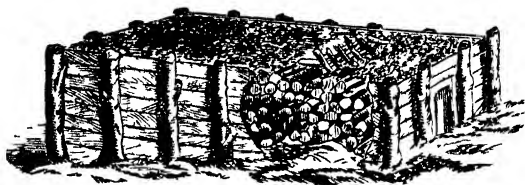
Fig. 5.—Rectangular Pile for Charcoal Burning.

The zones of active carbonization during the process of charcoal burning in piles are tolerably well marked; thus, if the accompanying (fig. 6) be a section of the circular pile, it is lighted along the axis AB, and a row of vents opened along the surface at E, E, etc.; the air entering at the base takes the most direct and easiest course towards the vents, which will necessarily be through the mass of wood contained in the zone described by the revolution of EMAB around the vertical axis AB; since the mass of material between the chimney AB and the line EM will consist of the timber which has been dried and partially charred by the burning material introduced down AB, and so having a less volume than the original wood, there will be larger cavities or spaces between the pieces, and the air entering at the bottom, MM, will thereby find less obstruction through this part than other portions of the pile, and so carbonization proceeds most rapidly in this zone or area; the vents at E now being closed and

Fig. 6

others opened at F, F, the material between EM and FN is under the same relative condition that existed
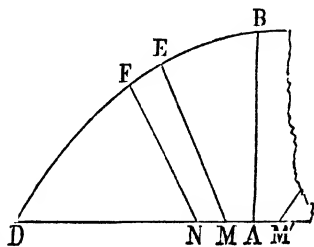
between AB and EM when the operation commenced; that is, the wood is dried and imperfectly charred from the heat developed by the carbonization of the previous zone, so that carbonization will now proceed in the area described by the revolution of the plane EMNF around the axis AB, the inclination of ME, NF, etc., to AD becoming successively less and less, *i.e.*, approaching at each step nearer and nearer to coincidence with the plane of the base of the pile; the carbonization thus proceeding from the centre towards the circumference of the pile.

In rectangular piles the process is much the same, the stack being ignited at the end A (fig. 7), and vents opened at E, decomposition proceeds in the area AMEB; when the openings at E are closed and others opened at F, the products of combustion, no longer having exit along EB, pass up through the section EMNF, completing the carbonization in this area; the vents in the same manner being closed at F and others opened at G, and so on successively to H, K, etc. ; the inclination of the boundary of the active zone, EM, FN, etc., continually approaches, as before, more and more towards horizontality.
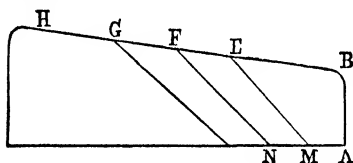
Fig. 7.

The heat necessary for the conduct of the operation is, to a large extent, derived from the combustion of the volatile products of the decomposition of the wood, and also, no doubt, to a small extent, by the actual burning away of a portion of the charcoal itself.

32. Peat Charcoal or Coke.—This product does not appear to be adapted to metallurgical purposes, its extreme friability rendering it unsuited for bearing any superincumbent pressure such as exists in blast furnaces, etc. It has been proposed to prepare peat charcoal by reducing the peat to pulp, forming the pulp so obtained into blocks, subjecting these blocks to pressure, and then carbonizing by the action of superheated steam; but the process has not been commercially successful.

33. Coke.—Coke is the carbonaceous residue left on the destructive distillation of coal, etc., and consists essentially of carbon, with the fixed earthy or inorganic constituents of the coal from which it is produced, retaining also a small proportion of oxygen, hydrogen, and nitrogen, and as occurring in commerce, it contains from 2 per cent. to 6 per cent. of water.

The average composition of coke, exclusive of ash, is

$$
\begin{array}{lll}
\text{Carbon} & = & 97\cdot33 \\
\text{Hydrogen} & = & \cdot35 \\
\text{Oxygen} & = & 2.32 \\
\hline
& & 100\cdot00
\end{array}
$$

Coke varies much in both its physical and chemical characters, depending upon the mode of coking and the quality of coal employed. It varies in colour from grey to black; some specimens are dull, while others are almost metallic in appearance, and sometimes iridescent; like wood charcoal it varies much in density, and it may be light, porous, and tender, or dense, hard, and resisting; the higher the temperature employed in its production, and the longer it is exposed to the heat, the harder, more dense, and, at the same time, less easily combustible will the coke become. The yield is also influenced by the temperature employed in its production, the higher the temperature employed, the greater will be the yield; this may possibly be affected to a limited degree, from the decomposition of hydrocarbon vapours arising from the distillation of the coal in the lower part of the pile, which, passing through the superincumbent heated mass, are decomposed, depositing their carbon as a lustrous coating on the coke, while the hydrogen only is burnt off. This increased yield can only occur from this cause when the temperature is sufficiently high to effect the decomposition of these vapours.

34. Coking in Piles.—This operation is conducted in circular piles of from 18 to 30 feet in diameter at the base, and from 5 feet to 6 feet at the chimney. In forming a stack of this kind, a chimney is first erected by placing four bricks in the form of a square, though not in contact, erecting short columns on these, and then completing the chimney by

placing bricks across the corners of each other, so as to leave spaces between the ends of each brick for the passage of gases, etc.   This chimney is closed either with a tile, or has a cast-iron damper applied as required. The large coal is then stacked around and leaning towards this centre chimney, outside of which again is placed the smaller coal ("lumps"). The pile thus built up is covered over to within a foot of the base with small coke dust; and live coals are now placed near the top of the chimney, the combustion rapidly extending downwards to the coal of the stack; thick smoke appears and issues through the covering; and as this smoke is replaced by the blue flame of carbonic oxide, the attendant applies coke-dust to that portion of the pile, and so checks or stops the combustion in that region; when the thick smoke has thus ceased to escape from every part of the pile, which occurs about the fifth or sixth day after firing, the chimney is perfectly closed, and the whole surface is plastered over with wet coke dust.   The pile is then left to cool down, and on about the tenth day it is watered and the coke drawn.
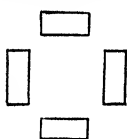
35. Coking in Kilns.—The kilns consist of two parallel walls A, A, 5 feet in height, and built about 8 feet apart inside, with

Fig. 8.
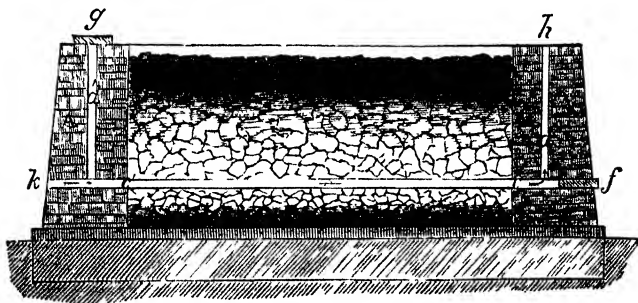
Fig. 9.—RECTANGULAR COKING KILN.

inner faces of fire-brick.   In these walls, at intervals of about 2 feet in the direction of their length, and at the same distance from the ground, are left transverse openings c, c',

those on opposite sides being kept in a line with one another; from each of these ascends a flue $d\ d'$, etc., to the top of the wall, these channels serve for regulating and directing the current of air through the kiln; as shown in the sketch, the current is entering at c', and passing out at d, since the other openings at c and d' are stopped by tiles, and thus, by inserting the tile f at c', and removing g to the opposite wall, the direction of the current will be reversed, and stopping all the four openings the entrance of air through this section of the kiln is prevented. To charge the kiln, one end is bricked up, and through the other coal slack is wheeled, then watered and stamped into the bottom of the kiln to the level of the openings c, c', etc.; stakes of wood are now inserted transversely across the kiln from each of the openings c, c', reaching into the opening in the opposite wall, when coal is wheeled in, watered, and stamped down as before, until the whole space between the walls is filled; the end is now bricked up, and the top covered with coal dust or loam, when the stakes of wood are withdrawn, leaving channels through the mass, into each of those on one side of the kiln is inserted readily inflammable sticks for lighting the kiln; suppose these sticks inserted at the side c', then the damper is placed at d' and in f, so as to direct the flame in the direction of the arrow, in the course of a few hours the fire will have extended across the kiln, the plates are then removed from g and f and placed at h and k, so as to direct the current in the reverse direction; the direction of the current is now regularly changed after every two to four hours according to the weather, unless the coking on one side be observed to be proceeding more rapidly than on the other, in which case the flues are kept open longer on the one side necessary to regulate the process. In about eight days a white flame escapes from the flues, and the process is judged to be completed; the whole of the openings are now closed, and in about two days longer the fire will have died out, when the end walls are taken down, and the coke drawn.

36. Coking in Ovens.—Coke ovens differ much in their size, form, and construction; the ordinary oven is a circular, rectangular, or oval chamber of fire-brick or other refractory material, in which coal is subjected to a process of dry distil-

lation.   The circular oven is a building of about 10 feet in diameter at the base, and about 5 feet high; around the floor of the oven a wall about 19 inches high is raised, from which springs an arch or dome of brickwork, having an opening at its summit which forms the opening for the introduction of the coal in charging, and also acts as a chimney during the coking operations (the floor of the oven is about 3 feet from the ground, so that trucks may be run up to the oven and the coke raked out into them); around this structure are built four thick walls of rough stone, forming the whole into a square block, the corners between these walls and the circular building being filled in with sand, rubbish, etc., so as to exclude air from the oven, and give greater stability to the structure; while in one end of the oven is a doorway or opening, bricked up loosely during the coking operations, and through which the charge is withdrawn.   The charge of about two tons of small refuse coal being introduced and spread over the floor by iron rakes, the end opening is loosely bricked up, so that only sufficient air may obtain access to the interior for the combustion of the volatile products; the oven being hot from the working off of a previous charge, decomposition quickly commences, and in two or three hours it is necessary to plaster over the greater part of the doorway with a mixture of wet soil and sand to check the admission of air, the combustion becoming too vigorous; and after about twenty-four hours the door is entirely plastered over; in twelve hours longer the flame which has been issuing from the chimney at the top of the oven disappears, and the chimney is stopped with stones and earth; when, after standing twelve hours longer, the coke is ready for drawing.   These ovens, when in fire, work continuously night and day.

Cox's coke oven is constructed with the view of retaining as much as possible of the heat produced during the coking operation, and utilizing the heat so stored up for working off the succeeding charge.   For this purpose the ovens, built in two rows back to back, with a chimney between each pair, have a double roof consisting of two arches, the one above the other, with a space between the two, through which the gases pass from the coking chamber proper before reaching

the chimney; on the second or upper arch is placed a considerable mass of sand or grit for still further increasing the mass of material to extract the heat from the escaping gases. The coking chamber is nearly rectangular, but slightly wider at the front end than at the rear, and the floor inclines from the back to the front, this form being adopted to facilitate the withdrawal of the coke; this chamber is bricked up at the rear end, and closed at the front end with a movable door, swung as an ordinary furnace door; at each side of, but exterior to the chamber and opening to the front, is an opening communicating by a channel in the brickwork with the back of the furnace, where three holes open from it into the coking chamber; these openings are for the admission of air, which is thus drawn from the front, but only obtains access to the oven after passing along the heated sides to the back, whence the heated air entering the chamber passes forwards, and then returns through the space between the two arches, and so to the stack. The charge introduced at the mouth of the chamber or oven is spread to a uniform depth, and the door is then closed and luted; the amount of air drawn through the oven being regulated by a damper in the stack. The coking being completed, the product is quenched by injecting water into the oven, after which the coke is drawn out in one mass by a drag inserted at the charging of the oven, and which only requires coupling to an external arrangement of mechanism to draw the mass bodily from the oven.

37. Appolt Coke Oven.—This consists really of twelve vertical retorts, chambers, or ovens of brickwork, arranged in two rows of six each; each oven is surrounded by an air-space of from $7\frac{1}{2}$ to 10 inches in width, and the chambers themselves are taper, measuring about 1 foot 1 inch by 3 feet 8 inches at the upper end, and 1 foot 6 inches by 4 feet at the base or lower end; each retort is provided with a cast-iron door at the bottom, serving to close its lower end, and which door opens downwards into an arched vault or chamber running the whole length under each row of six retorts, into which the coke falls when this door is allowed to fall open at the end of the coking operation. The twelve retorts of this oven are contained within four walls of brickwork,

between which and another massive brick wall, forming the exterior of the whole kiln, is a space filled up with loosely pulverized non-conducting matter, which allows of the expansion and contraction of the brickwork within as the coking operations proceed. The air-spaces surrounding each of these vertical chambers communicate with one another, forming one large divided chamber which also communicates, by means of openings left in the brickwork, with the interior of the retorts themselves; the gaseous and volatile products of the decomposition of the coal obtain in this manner access to this outer chamber, where their combustion is effected by admitting atmospheric air through holes in the outer sides of the kiln or oven; the products of combustion passing along flues left in the long side walls of the oven to the stacks, of which there is one to each row of six retorts.

The oven being heated from a previous charge, the coal is introduced at the top, the cover of which is then luted on with clay or coke dust; decomposition is immediately set up by the contact of the coal with the heated walls, and the gases escaping into the surrounding chamber are there burnt, the heat thus developed being sufficient to maintain the temperature of the oven sufficiently high to carry on the carbonization or coking continuously. In twenty-four hours after introducing the charge the carbonization is complete, the coke is drawn from that compartment, and the compartment or retort immediately recharged. If the oven is not already heated from previous working, it is necessary to insert temporary bars into the bottom of each compartment or retort and introduce a moderate fire, which is kept up for eight or ten days; the gases pass through the air-spaces, and so heat the walls of the oven; after this time the oven has attained the proper temperature of 1200° C. to 1400° C. and is ready for charging with coal for the coking process.

In this oven it will be noticed that the products of combustion are burnt on the exterior of each compartment, and not in the interior of the vessel, as in Cox's and most other coking retorts.

38. Waste Gases of Coke Ovens.—These gases consist of carbonic acid (CO_2), carbonic oxide (CO), marsh gas (CH_4), hydrogen (H), and nitrogen; the proportions of which

vary at different periods of the coking process, but the nitrogen averages about 80 per cent. of the total volume of the gases, carbonic acid from 10 per cent. to 12 per cent., carbonic oxide from 2 per cent. to 5 per cent., hydrogen from 1 per cent. to 6 per cent., and marsh gas about 1 per cent.; the proportions of hydrogen, carbonic oxide, and marsh gas, appear to decrease towards the end of the operation, while the nitrogen increases in quantity. It has been proposed to utilize the heat contained in the waste gases of coke ovens, by directing them beneath boilers for the generation of steam, but the attempts have hitherto not been quite successful.

39. Coking of Non-Caking Coals.—The process of making coke from non-caking coal slack, by first mixing it with coal-tar, pitch, etc., has been patented on several occasions. The coal (non-caking, as anthracite, etc.) is broken into small pieces, washed and mixed with one-fourth of its weight of coal-tar or pitch, and then converted into coke either in piles or ovens.

Coke may be obtained from non-caking coals rich in oxygen by heating them rapidly to a high temperature, but on the large scale no economical method of getting up the temperature with sufficient rapidity has been devised. A good coke may be obtained by coking a mixture of non-caking coal slack and caking coals together. Attempts have been made to coke non-caking coals by mixing 1 ton of pitch with 4 tons of coal and then coking, but the coking operation is irritating to the eyes of the workmen.

40. Patent Fuels.—Numerous patents have been taken out for the utilization of coal slack and coaly matters of various kinds ; in one process the small coal is tipped into a chamber or kind of funnel, from whence it passes to a disintegrator or mill, from which it is received by an elevator and passed to a hopper and onwards to a pug mill, where it is mixed with a mucilage consisting of 8 lbs. of farina to 1 lb. of carbolic acid ; the mixture being then coked in ovens. In another and more recent patent the coaly matter is mixed with about 5 per cent. of clay, the mixture is pressed into large bricks, these placed to saturate in a solution of resin in benzin, and after withdrawal require only to be dried. Recent experiments have been made to utilize peat by mixing

it in a state of powder with small coal and sawdust, and then pressing the mixture into blocks.

41. Sulphur in Coke.—For those operations in which the fuel (coke) is burned while in contact with the metal, as in the cupola for melting iron, etc., it is often necessary that the coke be as free as possible from *sulphur*. If the coal, previous to coking, contains iron pyrites (FeS_2), as is frequently the case, the effect of the coking operation will be to reduce this compound to the protosulphide of iron (FeS), which will remain in the coke unless removed by some further treatment. For this purpose, before drawing the coke from coke ovens, or immediately after drawing, and while the coke is still red hot, it is a usual practice to throw a considerable quantity of water upon the mass; when with sulphurous coke, the odour of sulphuretted hydrogen (SH_2) will be immediately observed, the sulphide of iron in contact with vapour of water suffering decomposition at a red heat, in this manner a partial removal of the sulphur from the coke is effected; in other cases the bottom of the oven has been formed of open bars, to admit of the introduction of superheated steam during the coking, with the view of removing the sulphur; but obviously this can only very partially succeed, except with exceedingly porous coke or charcoal, which will allow of their free permeation by the steam, also if an excess of steam be introduced it gives rise to a loss of carbon, the steam at this temperature being decomposed by the coke. The use of common salt ($NaCl$) has been patented for the *desulphurization* of coke, in which process the coal for coking is mixed with common salt, when on coking the sulphide of iron (FeS) is decomposed with the conversion of the iron into chloride, which, in contact with vapour of water at a high temperature, is resolved into hydrochloric acid and oxide of iron.

42. Calorific Power of Fuel.—The calorific power of a body is an expression indicating the number of parts, by weight of water, which can be raised through one thermometric degree by the combustion of one part, by weight, of the substance. The unit of weight employed is immaterial, it may be a grain, gramme, pound, or a ton; but in order that the figures for different substances may be compared with

each other, it is necessary that the water be always raised from the same temperature, since the amount of heat required to raise 1 lb. of water from 0°C. to 1°C. is not the same as is required to raise the same weight from 100°C. to 101°C. For the comparison of the calorific heats of fuels, the amount of water which *one* part by weight of *carbon*, in the form of purified wood charcoal, in burning to the state of *carbonic acid*, can raise through 1°C.—viz., from 0°C. to 1°C., is taken as the standard of comparison, and this is found by direct experiment to be 8080 units, *i.e.*, one part by weight of carbon in burning to its highest state of oxidation, viz., *carbonic acid* generates an amount of heat sufficient to raise 8080 parts of water from 0°C. to 1°C. In like manner, one part by weight of hydrogen on its combustion with oxygen to form water, generates heat sufficient to raise 34,462 parts by weight of water from 0°C. to 1°C.; 8080 and 34,462 are then the *calorific powers* of carbon and hydrogen respectively, from which it appears that *hydrogen* has a calorific power 4·265 times as great as *carbon*.[*]

Berthier estimated the calorific power of a fuel by heating it with protoxide of lead in a crucible from which he excluded the atmosphere carefully, when, the reduction being completed, the weight of the resulting button of lead enabled him to determine the amount of oxygen which had been consumed by the fuel in its combustion; then assuming that the calorific powers of bodies were proportional to the amounts of oxygen required for their combustion, he was enabled to obtain a comparison between the different fuels. The latter supposition, as exemplified in the case below, of carbon burning to the state of carbonic acid and carbonic oxide respectively, has been shown not to hold, and accordingly the method is not reliable.

The *calorific power* of *carbonic oxide* (CO) when burnt to *carbonic acid* (CO_2), as determined by Favre and Silberman is 2403 units; the amount of *carbon* in carbonic oxide $= \frac{1\,2}{2\,8} = \frac{3}{7}$

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[*] If the increment of temperature be taken as 1°F., *i.e.*, from 32°F. to 33°F. instead of from 0°C. to 1°C., then the numbers representing the calorific powers require to be increased in the proportion of 9 to 5, or the calorific powers of carbon and hydrogen become 14,544 and 62,031·6 respectively.

of its weight, hence to supply 1 lb. of carbon will require $\frac{7}{3}$ lbs. of carbonic oxide, and therefore $\frac{7}{3} \times 2403 = 5607$ units will represent the amount of heat generated by the combustion of a quantity of carbonic oxide containing the unit of weight of carbon. But one part or unit of carbon in burning to *carbonic acid* generates 8080 units of heat, hence in burning to the state of carbonic oxide, it generates only $8080 - 5607 = 2473$ units of heat; that is, the calorific power of carbon, when burned only to *carbonic oxide*, is *less* than one-third of what it is when burned to its maximum state of oxidation, *carbonic acid*.

The *calorific power* of a compound, as determined by experiment, is in general *less* than the sum of the calorific powers of its elements, with the *exception* of *olefiant* gas (C_2H_4), which gives the same figure both by calculation and experiment: all other hydrocarbons follow this general rule. The calorific power of marsh gas (CH_4) is found by experiment to be 13,063, as against 14,675·5 calculated from its composition.

The calorific power of a fuel depends upon the amount of *combustible* carbon and hydrogen which it yields. In the calculation of the heat-giving quality for a fuel containing carbon, hydrogen, and oxygen, the latter element must be considered to exist in combination with an amount of hydrogen sufficient to convert it into water, and therefore it is only the *excess of carbon* and *hydrogen* after this deduction that is available for the generation of heat on the combustion of the fuel. Thus, to calculate the calorific power of dry wood, the average ultimate analysis of which gives approximately—

Carbon	. .	= 50
Hydrogen	. .	= 6
Oxygen	. .	= 41
Nitrogen and Ash	=	3
		100

Each equivalent of oxygen requires $\frac{1}{8}$th of its weight of hydrogen for conversion into water, hence the 41 of oxygen will require $\frac{41}{8} = 5\cdot01$ of hydrogen for its conversion into water, which amount is therefore lost for the generation of

heat, and the amount of hydrogen available for the production of heat is only $6 - 5 = 1$ per cent.

Hence on burning 100 parts of this dry wood the

Carbon would generate . . $50 \times 8080 = 404000$ units of Ht.
Hydrogen in excess would generate $1 \times 34000 = 34000$ units of Ht.
Total, $= 438000$ units of Ht.

From this sum requires to be deducted the amount of heat rendered latent by the water supposed to pre-exist in the wood, owing to its containing oxygen $= 41 + 5 = 46$ per cent. of the wood, as also of the amount generated by the combustion of the one part of hydrogen existing in excess, and equivalent to $1 + 8 = 9$ per cent., or altogether there are 55 parts of water per 100 of the fuel to be heated at the expense of the heat of combustion; the latent heat of water is $537°$C., therefore the heat rendered latent by the water $= 55 \times 537 = 29,500$ units of heat, thus the available heat, excluding the nitrogen and ash, in 100 parts of the fuel $= 438,000 - 29,500 = 408,500$ units; hence the calorific power or heat evolved on the perfect combustion of one part by weight of this fuel is 4085 units. If the fuel be not thoroughly dessicated, but contains a sensible amount of hygroscopic water, then in addition to the latent heat of the water calculated as above, it will be necessary to deduct the heat rendered latent by this hygroscopic water.

From these calculations it is obvious that the *greater* the amount of *oxygen* contained in a fuel, the *smaller* will be its *calorific power*, since its presence not only directly reduces the actual percentage of carbon and hydrogen present in the fuel, but also renders a proportion of these heat-giving elements unavailable for the generation of heat.

43. Calorific Intensity.—The *calorific intensity, thermal effect*, or *actual temperature* of the products of combustion, does not depend entirely upon the amount of fuel consumed, or the *calorific power* of the fuel, but involves the consideration of the weight and nature of the products of combustion, as also of the rapidity and facility with which the fuel burns; thus in the blast furnace the products of combustion are the same whether *hot* or *cold* blast is employed, but the *calorific intensity* is *much greater* in the hot blast from the

more rapid combustion effected. The heat generated in combustion being in every instance first communicated to the products of combustion, usually gaseous, it is evident that as the specific heats of gases and vapours differ, so the temperature of these products will vary with their composition. Thus, if pure carbon be burned in oxygen, of which it requires for its combustion 2·67 times its own weight, the product is 3·67 times its weight of carbonic acid, and the heat of combustion is used for raising the temperature of this gas. Now one part by weight of carbon on perfect combustion generates heat sufficient to raise 8080 times its weight of water from 0°C. to 1°C., or 3·67 times its weight to $\frac{8080}{3\cdot67} = 2201\cdot63$°C. Hence if the capacity for heat of carbonic acid and water were the same, the product of combustion should have a temperature of 2201·63°C. at the moment of its production; but taking the specific heat of water at unity, then carbonic acid has a specific heat of ·2164, hence the temperature of the 3·67 parts by weight of carbonic acid generated by the combustion in oxygen of one part by weight of carbon would have theoretically at the moment of its production a temperature of $\frac{2201\cdot63}{\cdot2164} = 10173\cdot6$°C., thus the maximum theoretical temperature or *calorific intensity* of carbon $= \frac{8080}{3\cdot67 \times \cdot2164} = 10173\cdot6$°C.

If, as in the case of hydrogen, the product of combustion be a *condensible* vapour, it is necessary to deduct from the calorific power of the combustible elements the amount of heat rendered latent by the vapour, or necessary to retain the product in the vaporous form, as in the following example of the combustion of hydrogen in oxygen :—

		Heat Units.
Total heat of combustion of a unit of hydrogen		$= 34462$
Heat rendered latent by the water vapour produced on its combustion	$= 9 \times 537$	$= 4833$
Specific heat of water vapour		$= \cdot475$

$$\therefore \text{ Calorific intensity in case of hydrogen} = \frac{34462 - 4833}{9 \times \cdot475}$$
$$= 6930\cdot7°C.$$

Thus, although the *calorific powers* of carbon and hydrogen are respectively 8080 and 34,462, the *calorific intensities* are 10,173·6°C. and 6930·7°C. respectively, showing that though

hydrogen has much the higher *calorific power*, that its *calorific intensity* is much below that of carbon, and thus where intense local heat is required, a fuel containing a large proportion of carbon with a small amount of hydrogen is preferable.

If the fuel be consumed in a mixture of oxygen and nitrogen, as in atmospheric air, then if

T = increase of temperature produced by combustion.

C = amount of carbon in one part by weight of the fuel.

H = amount of hydrogen available for the generation of heat in one part by weight of the fuel.

3·67 C will be amount of carbonic acid produced by the combustion of the carbon.

9 H = the amount of water produced by the combustion of the hydrogen.

l = latent heat of water.

s, s', s'' = specific heats of carbonic acid, water vapour, and nitrogen.

N = quantity of nitrogen in the amount of air containing the necessary oxygen for the combustion of one part by weight of the fuel, so as to yield carbonic acid and water.

then $T = \dfrac{8080C + 34462H - 9Hl}{3·67Cs + 9Hs' + Ns''}$

If any solid *inert* body, as ashes, etc., be present in the fuel, its amount multiplied by its specific heat should be added to the denominator of this last equation.

In all cases the thermal effects above indicated are considerably in excess of those produced in our furnaces, since a very considerable excess of air is always introduced, and the heat of the fuel is accordingly distributed over a much greater weight of gas than is required for the perfect combustion of the fuel, with a consequent cooling effect. Other sources of loss in calorific intensity are due to the presence of inorganic matter or ash in the fuel, to loss from radiation and conduction by the material of the furnace, and lastly from imperfect combustion, due to the burning of coals in thick layers, or with an insufficient supply of air at the proper periods, when a large amount of carbon is only oxidized to the state of carbonic oxide with the corresponding loss of heat previously indicated.

44. Selection of Fuel.—The quality of a fuel, as an economical source of heat, cannot be determined entirely from the chemical analysis and the theoretical computation of its

calorific power as based thereon, since much of its value will
depend upon the manner in which it burns; whether it boils,
swells up, and agglutinates together to an excessive degree,
preventing thereby the free passage of air through the burning
mass, and necessitating continued stirring with its attendant
loss; or whether it lies loosely on the bars during combustion
without an undue amount of this pasty cohesion, allowing
the air to permeate it freely, and thus consume the coal more
completely.   To the former class belong the soft bituminous
coals, containing but little ash, while to the latter class
belong some of the harder and poorer coals, which thus, from
their manner of combustion, compensate for their deficiency
in carbon and hydrogen as compared with the former.

46. **Economy in Fuel.**—A considerable economy in the item
of fuel for certain operations, as in *puddling* and *reheating*
furnaces, is reported by the introduction of *regenerative gas-
furnaces* under various forms, these furnaces utilizing the
poorest classes of fuel, as coal slack, coke dust, peat, or lignite.
The use of revolving puddling furnaces, as those of Danks
and others, are also attended with an economy in fuel.   The
consideration of these furnaces will be found under the sub-
ject of " Iron."

By the introduction of the " Bessemer Process" for the
manufacture of steel, a saving in fuel has been effected esti-
mated at a million tons of coal annually.

CHAPTER IV.

IRON.

METALLIC IRON in a state of purity is comparatively little known, and void of commercial importance ; but its combinations with *carbon*, modified by the presence of other elements, constituting it *malleable iron, steel,* and *cast* or *pig-iron*, are of very considerable practical utility ; the consideration of the composition and properties of these varieties will be treated of in future chapters, the present one being confined to the consideration of the pure metal and the points of metallurgical interest in the compounds formed by its combinations with the other elements, metallic and non-metallic.

Pure iron, which is only prepared as a chemical curiosity, may be obtained by heating pure ferric oxide (Fe_2O_3) in a current of hydrogen gas; by heating to whiteness in a closed crucible a mixture of iron wire or iron-filings with magnetic oxide of iron covered with a layer of glass, or by the electrolytic decomposition of a solution of ferrous chloride. As obtained by the first method, employing only a dull red heat, the metal forms a dark grey powder, which takes fire in the atmosphere if slightly heated ; reduced at a higher temperature the metal is almost silver white, capable of receiving a high polish, and is no longer pyrophoric. Pure iron is softer than ordinary malleable iron, and its malleability is unaffected by heating to redness and sudden cooling, neither is it hardened by this treatment ; it is very tenacious and ductile, has a scaly or crystalline fracture, is scarcely acted upon by sulphuric or hydrochloric acids at the ordinary temperature, but if heat be applied it is dissolved with the evolution of hydrogen. Its magnetic power is very high, but it does not retain its magnetism ; its specific heat is ·113795, and the

specific gravity of electro-deposited iron is 7·675, which, after rolling, is somewhat less. If wrought-iron be melted and allowed to cool it is always crystalline on fracture, exhibiting faces of the cube; if rolled or hammered out, however, a fibrous structure is developed. The electrical conductivity of iron is higher the freer it is from impurities. The melting point of pure iron has not been decided with any degree of certainty, but it is fusible at a temperature below the melting point of platinum, and the purer the metal, especially its freedom from carbon, the higher is the temperature required for its fusion. Iron is not affected in dry air at the ordinary temperature, except when in a very fine state of division, such as exists when it is reduced at a low heat from ferric oxide by hydrogen, when it takes fire spontaneously; but it is rapidly oxidized by the joint action of air and moisture; heated to redness in contact with the atmosphere, it is oxidized rapidly. Water deprived of air or free oxygen does not affect iron at the ordinary temperature, but the finely divided metal decomposes it at a temperature below its boiling point; and the oxidation of iron by water is further promoted by the presence of carbonic acid, water holding carbonic acid in solution, attacking it even in the absence of air or free oxygen. If a perfectly bright clean strip of iron be immersed in cold fuming nitric acid, it assumes the *passive* condition, that is, it may be left during any length of time immersed in the acid without any solution of the metal, whereas ordinary nitric acid attacks the metal vigorously. Iron, as also its carbides, as steel and cast-iron, appear to have the power of *occluding* certain gases while in the fused state, which are, to a certain extent, liberated as the metal solidifies. The chemical symbol of iron is Fe, and its atomic weight is 56 (or if oxygen be taken as 8, the atomic weight of iron is 28).

**46. Iron and Oxygen.**—Iron combines with oxygen in several proportions, of which the most important are *ferrous oxide* (FeO), *ferric oxide* (Fe$_2$O$_3$), and the combination of these two, constituting *magnetic oxide*. The first named is a very unstable compound obtained, according to Debray, as a black non-magnetic body, when steam and hydrogen in certain proportions are passed over heated sesquioxide of iron. The *hydrated*

oxide or *ferrous hydrate* is obtained as a white flocculent precipitate when potash or soda is added to a solution of a ferrous salt, the precipitate absorbing oxygen almost immediately, changing thereby to green and then to brown. Ferrous oxide is a powerful base, and enters largely into the composition of the various *slags*, *cinders*, etc., produced in the metallurgical treatment of iron ; and by its combination with acids produces an important series of salts known as ferrous, or proto-salts of iron, which decompose on exposure to the atmosphere with the production of basic salts of ferric oxide. Of ferrous salts, the most important to the metallurgist are the carbonate and the sulphate; the former occurs anhydrous and crystallized in *spathic ore* or *siderite* and amorphous, along with clay, lime, etc., in the various clay ironstones. The carbonate suffers decomposition on heating to redness with access of air, carbonic oxide and carbonic acid being evolved, while magnetic oxide remains. Carbonate of iron is slightly soluble in water, but more so in water containing carbonic acid, which solution, on exposure to air, is decomposed with the precipitation of ferric oxide (hydrated).

47. Ferrous Sulphate.—Ferrous sulphate or proto-sulphate of iron occurs in commerce in the form of pale green crystals containing seven equivalents of water, which they lose more or less completely on heating, according to the temperature applied ; the first application of heat being attended with the melting of the crystals in their water of crystallization, heated further and the salt loses six equivalents of water, when a further increase in the temperature is attended with the production of an anhydrous gritty powder, and if exposed to a still stronger heat the salt suffers decomposition, a bright red pulverulent mass of ferric oxide (Fe_2O_3), called commercially *rouge* or *colcothar*, is obtained, while sulphurous acid (SO_2), and anhydrous sulphuric acid are evolved. Ferrous sulphate is formed when a sulphide of iron is exposed for some time to moist air, also when a sulphide is roasted at a low temperature with free access of air.

48. Ferric Oxide.—Ferric oxide (Fe_2O_3), called also *red oxide of iron*, exists in the anhydrous state in the minerals *hæmatite, iron glance, specular iron, micaceous iron ore,* and in the commercial oxide known as *rouge* or *colcothar*, pre-

pared by heating ferrous sulphate as above, with subsequent levigation, or by heating ferrous sulphate and sodic chloride (NaCl), or by simply heating the nitrate or oxalate of iron. Ferric oxide crystallizes in rhombohedrons ; but, as occurring in the mineral *martite*, it crystallizes in cubic forms, has a steel grey colour with a bright lustre, but the powdered substance is always red ; the artificial varieties are usually non-magnetic. Ferric oxide is very stable, and is not volatile ; but if heated to nearly a white heat it suffers decomposition, liberating oxygen, and leaving a fixed residue of magnetic oxide.

$$3Fe_2O_3 = 2Fe_3O_4 + O$$
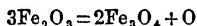
Ferric oxide is reduced to the metallic state by heating with *carbon, carbonic oxide, hydrogen, ammonia,* or *cyanogen;* if heated with excess of sulphur, ferrous sulphide is obtained with the evolution of sulphurous anhydride (SO_2). Ferric oxide is soluble in hydrochloric, nitric, and sulphuric acids, producing thereby a class of stable compounds known as ferric salts ; but it is only very slowly acted upon by mineral acids if subjected to a previous ignition. This oxide is used as a colouring material for glass and porcelain, to which it imparts a purple red or orange yellow colour, according to its treatment.

Hydrated ferric oxide ($Fe_2O_3, 3H_2O$) is precipitated as a bulky reddish brown precipitate, when potash, soda, or ammonia is added to a solution of a ferric salt, in which form it is amorphous, readily soluble in acids, and slightly soluble in water containing carbonic acid ; if kept under water for a considerable time it loses a portion of its water of composition, and if heated in boiling water during seven or eight days it retains only one equivalent of water, when it assumes the form of a brick-red amorphous powder, but slightly acted upon by hydrochloric, nitric, or sulphuric acid. Hydrated ferric oxide occurs in the minerals and ores of iron known as *brown hæmatite, limonite, and göthite.*

49. Magnetic Oxide.—Magnetic oxide of iron (Fe_3O_4) occurs native as *magnetite,* a black lustrous mineral, having a black streak ; it crystallizes in the cubic system, is strongly magnetic in both the native and artificial varieties, is also in native specimens frequently polar. This oxide con-

stitutes the ordinary *iron scale* or *hammer slag*, and is produced when iron is heated to redness in aqueous vapour, when iron is burned in oxygen gas, when ferrous sulphate with chloride of calcium are heated in covered crucibles (Kuhlman), or by the action of heat on ferrous silicate (Ebelmen).

When iron is oxidized by heating in contact with the atmosphere, two or three distinct layers of scale or slag form on the surface of the iron, which are readily detached, as by bending or hammering the metal, and of which the outer layer is more highly oxidized than the inner, and is slightly redder in tinge from the presence of a variable excess of ferric oxide over that contained in the inner layer. The oxide occurring in the outer layer of *hammer scale* is fusible only at a high temperature, is strongly magnetic, and slightly metallic in lustre ; while the inner layers are more porous, dull, and non-metallic in lustre, less brittle, and also less powerfully magnetic.

50. Ferric Acid.—This is the highest oxide of iron, and has never been prepared in a free state; but its combinations with alkalies, as ferrate of potash, may be obtained by fusing finely powdered iron filings with nitre, or in the wet way by passing chlorine through a concentrated solution of potash holding hydrated ferric oxide in suspension, potash being added from time to time to maintain the alkalinity of the solution. Ferrate of potash decomposes spontaneously, and if slightly heated decomposition ensues, even in vacuo, with the precipitation of ferric oxide; it is also decomposed by chlorine in excess, by ammonia, strong acids, and organic matters.

51. Iron and Sulphur.—Iron and sulphur have powerful affinities for each other, uniting directly under the influence of heat in varying proportions ; metallic iron heated with an excess of sulphur yielding ferrous sulphide (FeS), ferric sulphide (Fe_2S_3), disulphide of iron (FeS_2), or magnetic sulphide according to the temperature employed, the higher the heat applied, and the lower the degree of sulphuration in the product ; several other lower sulphides can also be obtained by special methods. Very small proportions of sulphur in malleable iron or steel suffice to induce in the

metal the property of *red shortness* or unworkability at a red heat, though it may be hammered or rolled while in the cold state with facility; while a small proportion, from 0·3 per cent. to 0·5 per cent. of sulphur, in cast-iron may be useful for foundry purposes, as producing a somewhat stronger iron as required for special castings; the peculiar dappled or reticulated appearance presented by the fractured surface of certain Swedish pig-irons is ascribed to the presence of sulphur; the addition of sulphur to grey pig-iron tending to the production of white iron.

Ferrous sulphide has not been found free in nature, but it exists in ores of nickel along with sulphide of nickel, and with sulphide of copper in copper pyrites; it is obtained artificially by the direct action of sulphur upon iron at a red heat, by igniting hammer scale with sulphur, by heating ferrous sulphate to a bright red heat in a crucible lined with charcoal, or by the precipitation of a ferrous salt with an alkaline sulphide. As obtained by the dry methods, it is a dark bronzy or black porous mass, having a semi-metallic lustre, and is not sensibly altered by exposure to the air at ordinary temperatures; but if gently heated it is converted partly into ferrous sulphate, which, at a stronger heat, is again decomposed with the production of ferric oxide and the evolution of sulphurous anhydride (SO_2). Aqueous vapour, passed over this sulphide, converts it into a black slightly magnetic mass, hydrogen and sulphuretted hydrogen SH_2 escaping. Ferrous sulphide heated with carbon is but slightly affected, with ferric oxide a portion of the sulphur is oxidized, but no metallic iron is separated; but if heated with ferrous or ferric sulphate in proper proportions, the sulphur from the whole of the ingredients is entirely eliminated as sulphurous acid (SO_2). When litharge (PbO) is fused with $\frac{1}{30}$th of its weight of ferrous sulphide, the sulphur escapes as sulphurous acid (SO_2), while metallic lead is separated beneath a layer of the fused oxides of iron and lead. Ferrous sulphide combines readily with other metallic sulphides on the application of heat, as will be exemplified in the metallurgy of copper. Silica is without action on this sulphide when heated with it, but if mixed with carbon, the sulphide is very largely decomposed.

52. Disulphide of Iron (FeS$_2$).—This compound occurs abundantly in nature, constituting *yellow iron pyrites, cubic pyrites* or *mundic*, and as *white iron pyrites, marcasite*, etc. The first named varieties occur as bronze or brass yellow, opaque solids, having a metallic lustre, and crystallizing in the cubic system, or as radiated, fibrous, or reniform masses. Marcasite or white iron pyrites is lighter in colour, approaching to whiteness, is usually softer than the yellow variety, and crystallizes in the rhombic system; this variety weathers very rapidly, while yellow pyrites in its compact forms does not sensibly alter by exposure to the atmosphere, but if finely divided it oxidizes rapidly with the formation of ferrous sulphate, the oxidation being attended with a rapid rise in the temperature, which, if allowed to rise too high, results in the evolution of sulphurous anhydride (SO$_2$), while ferric oxide remains. The residue from the combustion of iron pyrites in the manufacture of sulphuric acid is known as "*Blue Billy*," and is employed as an iron ore, and for the fettling of puddling furnaces in the Cleveland district.

53. Magnetic Pyrites, called also **pyrrhotine,** occurs native, often associated with ores of nickel and copper; it is of a colour between bronze yellow and copper red, with a metallic lustre quickly tarnishing, is slightly attracted by the magnet, and is often itself magnetic. This sulphide is obtained as a brownish yellow mass when the disulphide (iron pyrites) is heated to redness in a covered crucible.

54. Iron and Nitrogen.—The evidence concerning the existence of a chemical combination between these elements is exceedingly contradictory; Fremy, Savart, Despretz, and others state that when iron wire is heated for a considerable time in a current of ammonia, that the iron increases in weight with a diminution in its specific gravity, also that the iron so treated is white, brittle, and less alterable by exposure to the air than is the iron previous to this treatment; it is also still magnetic, soluble in acids, and can be hardened by heating and sudden cooling in water. Bois and Boussingault have examined commercial iron and steel for nitrogen, and state that they find from 0·005 per cent. to 0·124 per cent. of nitrogen in all irons.

55. Iron and Phosphorus. — These elements combine

readily under the influence of heat, producing grey or
whitish fusible compounds. Percy describes and formulates
seven compounds of phosphorus and iron, of which the
lowest one ($Fe_{12}P$) is formed when phosphorus and red hot
iron are brought into contact; while the third in his series,
having a constitution represented by Fe_4P, is metallurgically
the most important; it is obtained by heating phosphate of
iron with charcoal in a smith's fire or other source of intense
heat; as thus prepared it is very hard, brittle, capable of
receiving a high polish, and is only faintly magnetic.

The presence of only small quantities of phosphorus in
malleable iron and steel produces a marked effect in the
working qualities of the metal. Karsten states that 0·3 per
cent. of phosphorus in malleable iron, while not sensibly
affecting its tenacity, increases its hardness; that with 0·5 per
cent. the metal begins to show signs of deterioration, its ten-
acity manifestly diminishes, and it is sensibly *cold short*, that
is, cannot be worked under the hammer in the cold state
without cracking or breaking, though when heated it may
be rolled or hammered easily; with 0·75 per cent. of phos-
phorus the decrease in tenacity and cold shortness of the
metal are very decided, while the presence of 1 per cent.
renders wrought-iron exceedingly brittle and unusable, except
for special purposes. Phosphorus increases the hardness and
fluidity of pig-iron, and it is generally considered to render
pig-iron more largely crystalline on fracture; its average
quantity in foundry iron is about 1 per cent.

The presence of a notable quantity of phosphorus in iron
ores is especially objectionable, since this element passes
almost wholly into the pig-iron smelted therefrom, unless the
reduction be imperfect, and a highly basic slag containing
iron and a portion of the phosphorus in the state of phos-
phoric acid be allowed to form.

56. Iron and Arsenic.—These elements readily unite,
producing a series of compounds or arsenides of iron varying
from iron grey to white in colour, which are brittle and non-
magnetic, differing much in fusibility, and if roasted with
access of air, a large proportion of the arsenic escapes as a
sublimate of arsenious acid (As_2O_3), while basic arseniates re-
main behind. Arsenic, though not a very general impurity

in iron, occurs frequently in the metallurgical products known as *speise*, produced in the metallurgical treatment of the arsenical ores of nickel, cobalt, gold, silver, and lead, the speise so obtained being essentially an arsenide of iron. Arsenic, like sulphur, renders malleable iron *red-short*, but in pig metal, for producing chilled shot or other chilled castings, its presence has been stated to be advantageous. In Sweden and elsewhere articles are case-hardened by coating them with a paste of arsenious acid, powdered leather, horn, or other nitrogenous bodies, and hydrochloric acid, and then heating the articles so coated to bright redness in a muffle or other suitable furnace.

57. Iron and Silicon.—As already stated, the union of iron and silicon is not effected by the simple heating together of silica and iron, but in the presence of carbon, with a sufficiently high temperature the silicon is reduced, and in this manner Riley has succeeded in obtaining an alloy of silicon and iron, containing 21 per cent. of silicon, the metal so obtained being hard, brittle, highly crystalline, and light grey or silvery white in colour. Silicon is abstracted from pig-iron by fusion with ferric oxide (Fe_2O_3), and manganese, with the production of a manganous silicate.

Silicon is reduced in the blast furnace in larger or smaller proportion, according as the temperature of reduction is increased, as by the use of hot blast, etc., the silicon so reduced entering in considerable proportion into the pig-iron produced; and since an increase in the temperature of the furnace is a condition required for the production of grey pig-iron, as well as for the reduction of silicon, it is found that grey pig-iron is usually more highly silicious than white iron; the further consideration of its effect and amount is treated of under pig-iron. Silicon occurs usually only in small quantity in malleable iron and steel, to which, when present, it imparts hardness and brittleness, with a loss in tenacity.

The slags, cinders, etc., produced in the blast, puddling, refining, reheating, and other furnaces employed in the metallurgical manipulation of iron, are essentially oxidized products of silicon and iron, consisting for the most part of a ferrous silicate (silicate of protoxide of iron), containing about 30 per cent. of silica with 70 per cent. of ferrous oxide, the

latter replaced more or less by other bases, as manganous oxide, etc. ; on heating these slags or cinders with carbon, as by smelting in the blast furnace, Percy states that about two-thirds, or two out of the three equivalents of ferrous oxide present in the slag are reduced, the pig-iron so obtained being known as *cinder-pig*, to distinguish it from the iron smelted from pure *ore* or *mine*. When the tribasic silicate or slag is heated with access of air it is more or less completely converted into sesquioxide with the separation of the silica ; thus " bull dog," a very refractory dark grey, lustrous body employed in the lining of puddling furnaces, etc., and obtained by roasting " *tap cinder* " (the slag of the puddling furnace) during several days in kilns, somewhat resembling ordinary coke or brick-kilns, consists largely of a comparatively infusible ferric oxide (Fe_2O_3), with a small amount of silica ; during the roasting of the tap cinder two products melt and liquate out, both of which are more silicious than the "bull dog ;" the one known as " *bull dog slag* " collects in the bottom of the kiln, while the other, which runs out through openings in the side of the kiln, is highly silicious, and contains the largest proportion of the phosphoric acid always present in tap cinder.

58. Iron and Carbon.—Upon the degree of carburization of iron, modified by the presence of other elements, as sulphur, phosphorus, silicon, and manganese, depends the classification into cast-iron, steel, and malleable iron, with the widely different qualities possessed by these bodies ; in the first named the carbon may exist to the extent of a little over 5 per cent., while in the latter it may be almost entirely absent. Carbon and iron do not combine at ordinary temperatures, but if raised to a temperature *at* or *above* redness, combination between the two ensues with greater or less rapidity ; in the process of cementation for the production of steel, the bars of iron are heated to from 1000°C. to 1200°C. in contact with charcoal, when a combination of iron and carbon known as *blister steel* results. At ordinary furnace temperatures iron does not decompose carbonic oxide, but if the temperature be raised still higher, as in the blast furnace, carbonic oxide is decomposed, and a certain amount of its carbon enters into combination with the iron ; the *carburiza-*

tion of iron can also be effected by heating it in coal gas, the vapour of paraffine, and other volatile hydrocarbons ; or by heating malleable iron to a lower temperature in contact with carbonaceous matters, cyanogen compounds, etc., as in the operation of *case-hardening.* In cast or pig-iron, the carbon exists in all cases both as combined and graphitic carbon ; in *grey iron* the carbon exists almost wholly as graphite, which Mr. Snelus has shown can be detached from the crystals of iron, and separated therefrom by the mechanical operation of sifting ; but in *white iron,* as *speigeleisen,* the carbon is almost wholly combined, only a small quantity existing as graphite ; while in *mottled iron* the proportions of combined and graphitic carbon are more nearly in equality. Cast-iron in its fluid state is capable of holding an amount of carbon in solution, which, as the metal cools slowly, separates as graphite or *kish,* while if the metal be suddenly cooled the greater portion of the carbon is retained in combination with the iron.

59. Iron and Copper.—The direct union of iron and copper is attended with difficulty, but an apparently homogeneous alloy can be obtained by the simultaneous reduction of the *oxides* of iron and copper, taking-care that the oxide of iron be not in excess. The presence of 0·5 per cent. of *copper* in wrought-iron or steel renders it *red-short,* while 2 per cent. makes steel absolutely brittle, and ·0286 per cent. of copper sensibly diminishes the tenacity of malleable iron.

60. Iron and Zinc.—These metals yield, when heated together, a more or less crystalline, brittle, and friable alloy of no practical use ; but by immersing malleable iron freed from scale or rust by previous immersion in dilute sulphuric acid, in a bath of molten zinc covered with sal ammoniac (NH_4Cl), a thin coating or alloy of zinc and iron is deposited on the surface of the plate, whereby the iron is prevented from rust and corrosion on exposure to the atmosphere, and such plates, under the name of *galvanized* or *zinced* plates, are of extensive application in the arts.

61. Aich Metal.—This is an alloy consisting of about 60 per cent. of copper, with 38 to 44 per cent. of zinc, and from ·5 per cent. to 3 per cent. of iron, which can be rolled, hammered, or drawn into wire, is possessed of very considerable

tenacity, and said to resist the action of sea-water. A similar alloy, patented by *Keir*, is formed by melting under a layer of charcoal 100 parts of copper with 10 of iron, and to the bath so formed adding by degrees 75 parts of zinc; and *sterro-metal*, a brass yellow alloy of great elasticity and tensile strength, capable of being worked either hot or cold, and proposed as a material for the construction of ordnance, is a similar alloy, consisting of 60 per cent. of copper, with 34 to 44 per cent. of zinc, 2 to 4 per cent. of iron (malleable iron is used), and from 1 to 2 per cent. of tin.

62. Iron and Tin.—These metals when heated together combine in various proportions, producing alloys varying from grey to white in colour, with a granular or crystalline fracture, more or less brittle, and harder than tin. It has been proposed to harden the tops of rails by the addition of from ·1 per cent. to ·5 per cent. of tin to the puddler's charges when manufacturing iron for this purpose; but its use has not proved successful, the metal so produced being *cold-short*, brittle, difficult to weld, and could only be hammered at a red heat with great care. When a clean surface of sheet-iron is immersed in a bath of molten tin, a firm adherent coating of a highly stanniferous alloy is deposited on the surface, the plate so prepared constituting the ordinary *tin plate*.

63. Iron and Titanium.—The existence of an alloy of iron and titanium has not yet been definitely shown, though by the treatment of titaniferous iron ores in the blast furnace, pig-iron has been obtained, as will be subsequently described, containing upwards of 1 per cent. of *titanium*, either alloyed or disseminated through the iron; but the malleable iron or steel produced therefrom affords no evidence of its presence.

64. Iron and Manganese.—Very little is known of the alloy of pure iron and manganese; but manganese is a common constituent in pig-iron, its tendency, when in considerable proportion, being to render the pig white and more brittle. Mushet states that pig-iron containing 22 per cent. of manganese ceases to be magnetic. The presence of manganese in iron ores promotes the elimination of sulphur from the product obtained on smelting the ore, but does not appear to affect the proportion of the phosphorus.

65. Iron and Tungsten.—Tungsten reduced from tungstic acid in the presence of iron readily alloys with the latter; thus, when grey iron is heated to a very high temperature along with tungstic acid, the graphite of the pig-iron, by combination with the oxygen of the tungstic acid, reduces the metal, which, alloying with the iron, produces an exceedingly hard, fine grained, and almost silver white steel, which is more or less malleable according to the amount of tungsten present. If *speigeleisen* or *white* iron be substituted for grey iron, no sensible amount of the tungsten is reduced.

66. Iron and Lead.—No alloy of these two metals is satisfactorily known.

67. Iron and Antimony.—An alloy of antimony and iron always results as a *regulus* in the reduction of antimony from its sulphide by treatment with metallic iron in excess. The presence of from ·2 per cent. to ·3 per cent. of *antimony* in malleable iron suffices to render it both *hot* and *cold-short*.

68. Iron and Bismuth may be alloyed by melting together the two metals in certain proportions; but on puddling a bismuthic pig-iron, the bismuth would pass out into the slag.

69. Iron and Nickel.—The alloys of nickel and iron, as formed by the fusion of the two metals, or by the reduction of their mixed oxides, are whiter than iron, are magnetic, capable of receiving a high polish, not so easily affected by air and moisture, and retain the malleability of iron. A natural alloy of iron and nickel occurs in meteoric masses; and nickel, as also cobalt, frequently occurs in minute quantities in malleable iron.

70. Iron and Cobalt.—These metals alloy well together, and the product is similar in character to the last described alloy, but Hassenfratz describes it as being inclined to *red shortness*.

71. Iron and Silver.—Iron and silver do not appear to alloy well together; for although the mixture of the metals appears homogeneous while in the fluid state, after cooling the silver separates throughout the mass. Karsten says that *silver* induces *red shortness* in malleable iron.

72. Iron with Gold and Platinum.—These metals alloy well together, small quantities of iron added to gold increas-

ing its hardness. With platinum and steel an alloy may be obtained which is fusible at a temperature considerably below that required to melt steel ; and with 1 per cent. of platinum steel yields a tenacious, ductile, and very fine grained product.

73. Iron and Aluminum.—These metals may be alloyed in all proportions, but the compounds so produced are of no practical value in the arts ; aluminum, if present in malleable iron, steel, or cast-iron, occurs only in faint traces, and Karsten concludes that its presence would be to diminish the strength of the iron, a conclusion confirmed by the experiments of the author on alloys of aluminum and steel.

74. Iron and Chromium.—The alloys of iron and chromium are less fusible and less magnetic than iron alone. The addition of from 1 per cent. to 2 per cent of chromium appears to harden and slightly increase the tenacity and ductility of cast-steel.

CHAPTER V.

IRON ORES.

OF the minerals which occur in greatest abundance, and contain iron in large proportion, are the oxides, disulphide, carbonate, phosphate, titanate, and silicate of iron ; but for the extraction of the metal, the oxides and carbonates alone are extensively available, and these, accordingly, will only be noticed here, viz :—

75. Magnetic Iron Ore or Magnetite (Fe_3O_4).—This ore contains in its pure state 72·41 per cent. of iron, constituting it the richest ore available for iron smelting ; and it is from this, smelted with charcoal, that is obtained the famed Dannemora iron. Magnetite crystallizes in the cubic system, is of a black colour, and gives, when drawn over a slab of unglazed pottery-ware, or scratched by the knife, a black mark, this test being known in mineralogy as the *streak* of the mineral, which term will be adopted hereafter. It occurs massive with a crystalline or granular fracture, and also in the state of sand ; is strongly magnetic, and sometimes polar, by which quality it may be distinguished from chrome iron ore. Magnetic iron ore is very widely distributed, occurring abundantly in Norway, Sweden, Siberia, Canada, and the United States. It is also found in the west of England.

76. Franklinite is very similar to magnetite, but is less magnetic, and gives a dark reddish brown streak; the analyses of this ore by Rammelsberg show it to contain 45·16 per cent. of iron, 9·38 per cent. of manganese, and 20·30 per cent. of zinc, all existing as oxides; it occurs chiefly in the Silurian limestones of New Jersey in America, and several other of the United States, where it is treated for the extraction of zinc, and the residues so obtained smelted for speigeleisen, a highly manganiferous pig-iron.

77. Red Hæmatite.—This name is applied generally to minerals consisting essentially of anhydrous ferric oxide (Fe_2O_3); the crystallized varieties, as *specular iron ore or iron glance*, occurring in rhombohedral forms. Hæmatite varies in colour from bluish grey to deep red, but the streak is invariably red; in its pure state it contains 70 per cent. of iron, and, according to its physical characters, it has received various names; thus, the scaly or micaceous varieties, as those of Devon, are known as *micaceous iron ore;* the hard, massive, and reniform masses, having a fibrous or radiating structure, and occurring chiefly in the Cumberland district, are known as *kidney ore;* the more earthy varieties constitute *red ochre;* while the soft, unctuous, compact form constitutes the *puddler's ore* or *puddler's mine*, used for the fettling of puddling furnaces. The most important deposits of this ore in England occur in the permian and carboniferous rocks of Lancashire and Cumberland, where the mineral is classed as "hard" or "soft," according as it contains a large excess of free silica or otherwise; and it is now smelted largely in the vicinity of the mines, the pig-iron produced being highly suitable and much in demand for conversion into steel by the Bessemer process. Varieties of this ore also occur largely in the United States, Canada, Sweden, and Norway.

78. Brown Hæmatite, called also **Brown Iron Ore**, is an hydrated ferric oxide ($2Fe_2O_3$, $3OH_2$), usually compact or earthy, and of various shades of colour, from blackish to yellowish brown, with a dull lustre, and an invariable yellowish brown streak. *Bog ore* or *limonite, lake ore*, as also *göthite*, belong to this class, the latter a crystallized and very rich variety. Brown hæmatite contains, when pure, 59·89 per cent. of iron, and 14·44 per cent. of combined water, but it frequently contains manganese with more or less earthy impurities; it occurs abundantly in the carboniferous formation of the Forest of Dean, in Glamorganshire, in Devonshire, in Northamptonshire, and Lincolnshire; while in France and Germany it is one of the ores principally smelted. *Bog iron ore* usually contains a notable quantity of phosphorus, rendering the irons produced therefrom only applicable to foundry purposes; it is smelted largely in Canada; and the so-called *lake ores* are smelted in Sweden and Finland.

79. Spathic Ores. — Spathic or sparry ore is the term applied by metallurgists to the purer and more crystallized varieties of *ferrous carbonate* (CO_3, Fe_2), while the impure and argillaceous carbonates of the coal measures are known as *clay ironstones*, and if impregnated with much bituminous matter, as occurring in Scotland, the ore is then known as a *blackband* ironstone.

Spathic ores in their purest form, that is, as crystallized "*siderite*," contain 48·27 per cent. of iron, and vary in colour from white to yellow or brown, with a pearly lustre, but are frequently coated superficially with a layer of hydrated ferric oxide produced by the weathering of the carbonate ; the streak is white, and when crystallized they occur in the rhombohedral system ; in composition they vary much, but manganous oxide is almost invariably present, in some cases to the extent of 50 per cent. or upwards ; lime and magnesia are also frequent ingredients, and this ore often contains iron and copper pyrites in sensible proportions, the pig-iron (speigeleisen) produced therefrom most frequently containing small quantities of copper. Spathic carbonate of iron occurs in England in the carboniferous limestone of Durham, Cornwall, and the Brendon Hills, in Somersetshire ; on the Continent it occurs in some instances as mountain masses, as in the Siegen district of Prussia, in Styria and Westphalia, and to a smaller extent in Carinthia. This ore is now in considerable demand for the production of speigeleisen, for which purpose large quantities are shipped to South Wales for reduction, where the ore is picked and calcined for the purpose of expelling sulphur before smelting.

The argillaceous carbonate of iron or *clay ironstone* is compact, earthy or clay-like, varying in colour from light brown to black, the latter due to the presence of coaly or carbonaceous matters, amounting in the *blackband* varieties to 10, 20, or even 30 per cent. of the ore; like the spathic ore it consists largely of ferrous carbonate, with carbonate of manganese, lime, and magnesia, silicate of alumina (clay), potash, phosphoric acid, sulphuric acid, iron pyrites, and occasionally also zinc blende, galena, etc., along with water and organic matter. This ore occurs either in beds of considerable thickness and extent, or in detached nodules in

the clay and shales of the coal measures of North and South Staffordshire, North and South Wales, Yorkshire, Derbyshire, Warwickshire, Denbighshire, and Scotland, as also in the lias formation of Yorkshire. Nearly two-thirds of the total amount of the pig-iron produced in Great Britain is derived from this ore.

The *blackband* variety of ironstone often resembles cannel coal in appearance, containing sufficient bituminous matter to effect its own calcination without the further addition of fuel, and after which it contains about 60 per cent. of iron.

The pig-iron smelted from clay ironstone, without admixture with cinder, contains usually from 0·25 per cent. to 1·5 per cent. of phosphorus, and from ·02 per cent. to 0·1 per cent. of sulphur; but if cinder be added to the charge, as practised in South Wales for the production of common forge pig, the sulphur may reach 0·7 per cent.

80. Titaniferous Iron Ore or Ilmenite.—This mineral occurs massive, or forming sands nearly black in colour, and more rarely in rhombohedral crystals; it has a brown streak, and contains oxide of iron, titanic acid, with more or less magnesia; it is a very refractory material, difficult of treatment in the blast furnace, and has accordingly been tried as a material for lining the bed of revolving puddling chambers with tolerable success, and recently it has been treated in the American bloomery furnace for the production of malleable iron direct from the ore.

ANALYSES OF IRON ORES.

	MAGNETIC IRON ORES.		RED IRON ORES.		BROWN IRON ORES.		SPATHIC ORES.		CLAY IRONSTONE OF COAL MEASURE.			CLEVELAND ORE.
Locality	Dannemora Ore.	Dartmoor.	Ulverstone.	Barrow-in-Furness.	Forest of Dean.	Northampton.	Brendon Somersetshire.	Siegen.	Black-band, Low Moor.	Dudley, band, Gubion Ore.	Black-band, Monmouthshire.	Eston.
Analyst	Ward.	Riley.	Spiller.	Richards.	Dick.	Percy.	Spiller.	Schmidt.	Spiller.	Dick.	Rogers.	
Ferric oxide (Fe_2O_3),	27·55	62·20	94·23	94·88	90·05	56·20	0·81	...	1·45	0·40	4·10	3·60
Ferrous oxide (FeO),	58·93	17·32	0·23	0·04	0·08	trace	43·84	43·59	36·14	45·86	43·37	39·92
Manganous oxide (MnO),	0·10	0·14	0·63	0·07	0·14	0·20	12·64	17·87	1·38	0·96	1·50	0·95
Alumina,	0·29	3·81	0·05	0·34	0·06	2·43	0·01	...	6·74	5·86	6·05	7·86
Lime,	0·38	5·52	trace	trace	0·20	0·49	0·28	0·08	2·70	1·37	3·00	7·44
Magnesia,	0·61	1·82	...	...	...	0·17	3·63	0·24	2·17	1·85	0·25	3·82
Potash,	...	0·10	trace	trace	...	...	...	...	0·65	...	...	0·27
Silica,	12·54	9·66	4·90	4·55	0·92	29·07	0·07	...	17·37	10·68	...	8·76
Carbonic acid,	0·12	0·10	...	...	...	...	38·86	38·22	26·57	31·02	30·50	22·85
Phosphoric acid,	trace	...	trace	0·03	0·09	0·84	...	...	0·34	0·21	trace	1·86
Sulphuric acid,	...	...	0·09	...	traces	...	...	...	trace	trace	...	...
Sulphur,	0·04	0·07	0·03	...		...	...	...	0·10	0·10	...	0·11
Iron pyrites,	...	...	...	...	...	...	...	...	...	...	1·56	...
Water,	0·11	0·62	0·56	0·47	9·22	10·90	0·18	...	1·77	1·08	·58	2·97
Organic matter,	...	...	...	...	...	...	...	...	2·40	0·90	6·25	...
Insoluble residue,	...	...	...	...	...	...	...	...	...	...	2·80	...
Percentage of iron,	62·60	57·01	65·98	66·42	63·04	39·34	34·67	34·18	29·12	35·99	36·49	33·62

CHAPTER VI.

PIG OR CAST IRON.

WITH but few exceptions, which will be noted under malleable iron and steel respectively, the result of the treatment of iron ores with fluxes and reducing agents in the various furnaces is the production of a combination of iron with carbon, silicon, sulphur, phosphorus, and manganese, with occasional traces of arsenic, copper, titanium, chromium, cobalt, etc., and known as *pig-iron*, which is unforgeable, cannot be welded, and is almost void of ductility; its specific gravity ranging between 7·1 in grey pig-iron to 7·5 in white pig-iron, and melting at an average temperature of about 1530°C. (2786°F.)

In pig or cast-iron, iron attains its maximum degree of carburization, the amount of carbon varying from 2 per cent. to 5 per cent., the lower figure being just beyond the limit (about 1·8 per cent.) of hard cast-steel. Carbon may exist in pig-iron either in a state of chemical combination, or as flakes or crystals of graphite distributed in an uncombined state through the mass of iron, or partly combined and partly graphitic; under these conditions we have various grades of *white*, *grey*, and *mottled* pig-iron respectively. On treatment with acids these varieties behave very differently; *white* cast-iron is almost entirely dissolved, only a very small residue of graphite remaining, the bulk of its carbon escaping in combination with hydrogen, as mixtures of gaseous and liquid hydrocarbons, the latter being highly volatile, of a brown colour, soluble in alkalies, and possessing a most disagreeable odour; while *grey* pig-iron under the same condition deposits almost the whole of its carbon in the form of a graphitic insoluble residue. *Speigeleisen* or mirror iron, sometimes called also specular iron, is the most highly carburized

and crystalline form of white pig-iron ; its composition has given rise to much investigation as to whether it was not an atomic compound of iron and carbon of the composition Fe_4C, or, as it invariably contains a large proportion of manganese, whether it might not be a tetracarbide, in which a portion of the iron is always replaced by manganese, its formula being $(FeMn)_4C$. Some varieties of white pig-iron, in melting, pass through an intermediate pasty condition, in which the metal is more readily decarburized, and with less oxidation of the iron than occurs when iron is merely heated to redness, or when it is in a perfectly fused state, hence its preference for conversion by puddling into malleable iron. The action of atmospheric air, when blown through molten pig-iron, is to effect the removal of its carbon, silicon, and manganese, as will be described under the Bessemer process for the conversion of pig-iron into steel. Cast-iron is sensibly acted upon or corroded by immersion in sea water, especially if exposed to the combined action of sea water and air ; a porous mass remaining having the form of the original casting, but which in some cases after drying is spontaneously inflammable.

Grey pig, if suddenly cooled, becomes white ; and hence, on an examination of Swedish pigs, which are cast as rectangular plates in iron moulds, and thus chilled on the surface, it is found that, however grey the bulk of the metal may be, it usually exhibits on fracture a variable depth or skin of white iron, resulting from the chilling effect of the iron mould on the liquid metal, attended with the conversion of the carbon at the chilled surfaces wholly into combined carbon ; the white portion is also found to be poorer* in silicon than the upper or grey part. Grey pig-iron, owing to the higher temperature employed in its production, often contains larger amounts of foreign substances, as silicon, aluminum, magnesium, etc., than does white iron smelted from similar mixtures. If both white and grey iron be produced in the same furnace, and descend together to the hearth, the white iron, having a higher specific gravity, will separate and form the bottom layer ; hence, on tapping the furnace, the first metal will run out in a sluggish stream, accompanied by showers of sparks, and yielding pigs of white iron ; which may subsequently be succeeded by a

* Crooke's and Rohrig's *Metallurgy.*

perfectly fluid stream, unaccompanied by sparks, the product being foundry or grey pig-iron. The low temperature attained in the Swedish charcoal furnace, with the silicious slag produced therein, favours the production of light grey or mottled iron.

The table of analyses of pig-iron given on the next page, serves to show the average amount of its usual constituents, with the variation in its composition.

81. Cast-iron and Sulphur.—The presence of small quantities of sulphur in cast iron improves its strength for foundry purposes, though unfitting it for conversion into steel. In the smelting of Swedish gun-foundry iron, a small quantity of iron pyrites is introduced into the blast furnace along with the ordinary charge, whereby the fracture of the pig assumes a peculiar appearance as of grey iron traversed by a network of white iron; the cast-iron so obtained is specially adapted for the casting of ordnance. The presence of sulphur in iron tends to produce whiteness in the pig.

82. Cast-Iron and Phosphorus.—Phosphorus is very frequently present in pig-iron, sometimes to the extent of 2 per cent.; its effect is to render the pig-iron brittle, but more fusible, and to remain longer in the liquid condition after melting. If present in not too large proportion, it is advantageous in irons for many foundry purposes.

83. Cast-iron and Silicon. — Silicon, derived from the reduction of silica in the blast furnace, is present in almost all pig-irons, in amounts varying in ordinary pigs from 0·1 per cent. to 5 per cent., and in exceptional cases even 20 per cent. of this element may be introduced into a pig-iron, the metal then being highly crystalline and silvery white in colour; hot blast and grey irons contain the largest proportion of this element, while, owing to the low temperature produced in charcoal furnaces, the pig-iron produced in such contains a smaller proportion of silicon than occurs when coke is employed as the fuel; its quantity is further always increased when free *silica* exists in the charge, and an insufficiency of lime is added to combine with the excess, or when light *burdens*—that is, a large proportion of fuel to ore—are employed in the furnace. Silicon, like carbon, is capable of existing in the graphitic

ANALYSES OF CAST OR PIG IRON.

MATERIAL.	Graphitic Carbon	Combined Carbon	Silicon	Sulphur	Phosphorus	Manganese	Titanium	Copper	Iron.
No. 2 pig,	3·18		3·28	0·06	0·06	0·48	0·71	·	92·79
Pig-Iron Smelted from Northampton-shire ore with hot-blast (Henry).	1·50	0·554	1·900	0·414	1·807	0·305	...	...	93·780
Lancashire Bessemer pig, No 2 grey (Author),	2·579	1·175	1·738	0·014	0·038	0·130	...	...	94·304
Bowling No. 1 grey, cold-blast pig (Abel),	...	2·99	0·97	0·05	0·50	...	...	...	93·66
Cleveland No. 3 pig,	3·13	0·28	0·88	0·17	1·23	0·037	0·140	...	93·47
No. 1 pig, smelted from Hæmatite with 7·57 per cent. of Ilmenite (Riley),	3·31		1·86	0·06	0·08	0·50	1·15	...	93·611
Hæmatite Bessemer pig, No. 1 grey from Cleator, Cumberland (Author),	3·045	0·704	2·003	0·003	0·037	0·309	0·189	...	...
German Speigeleisen smelted with coke,		5·04	0·41	0·08	...	7·57	...	0·16	86·74
Mottled iron smelted with charcoal (Rosthorn),	2·02	1·43	0·92	0·04	0·04	2·02	Aluminium 0·40	...	94·08
Scotch hot-blast pig-iron (Schaffhautl),	2·45	2·00	2·23	0·18	0·25	0·21	Alumin. and magnesium traces.	...	88·983
Pontypool cold-blast grey pig (Woolwich Arsenal),	2·53	...	1·23	0·08	0·46	0·42	...	Calcium ·074	...
No. 4 Forge hot-blast iron (Stock),	2·719	1·222	1·608	0·031	0·016	0·021	...	...	94·309

condition, in which state it may occur in pig-irons smelted with hot-blast from ores difficult of reduction, while white or manganiferous pigs do not hold it in this condition. The presence of this element is very necessary in hæmatite pig-iron intended for the Bessemer process; but its presence in large quantity diminishes the strength of the pig-iron for foundry purposes.

84. Effect of other Metals on Pig-Iron.—The presence of *titanium* in pig-iron imparts additional strength to the metal, and gives a peculiar mottled appearance to the pig; it is rarely present to the extent of more than 1 per cent.

Vanadium has been detected in the pig-irons produced from certain ores of Taberg, in Sweden, oolitic ores of Wiltshire (Riley), etc.; its presence renders the iron soft, and yields an iron well adapted to wire-drawing.

Copper is frequently present in small quantities in pig-iron, especially in those brands (as speigeleisens) smelted from spathic ores; pig-iron containing copper is unfit for conversion into malleable iron or steel, but the presence of a small quantity, not exceeding 0·2 per cent., is said not to deteriorate its quality as a foundry pig.

Arsenic, chromium, aluminum, zinc, etc., are often present in pig-irons smelted from ores containing these metals, the first-named occasionally in considerable amount.

Pig-iron containing *tin* is hard, readily fused, and unfit for conversion into malleable iron, yielding a wrought iron exceedingly *cold-short.*

85. Commercial Classification. — Upon the colour, hardness, brittleness, and character of fracture depends chiefly the classification adopted in commerce of *grey, mottled,* and *white* or *specular* iron. The first variety is again subdivided in the Cleveland district, according to the degree of greyness, into No. 1, 2, 3, 4, 4 forge. No. 1 is the darkest grey, is soft and largely granular on fracture; in Nos. 2, 3, 4, the colour becomes gradually whiter, but duller in lustre, and the metal becomes more finely granular on fracture, until it passes insensibly into white iron, which has a more crystalline flaky appearance on fracture, is very much harder, and as in specular iron, or *speigeleisen,* is largely crystalline, exhibiting large lustrous cleavage planes on fracture. The mottled varieties, which stand intermediate between the

grey and white irons, exhibit on fracture a mottled or variegated aspect, from the presence of veins and small masses of white iron embedded, as it were, in a matrix of grey iron ; according to the amount of white iron present, the pig is characterised as *weakly* or *strongly* mottled, the latter approximating to white iron in appearance and character.

Grey iron requires a higher temperature (1600°C. to 1700°C.) for its fusion than does white iron (1400°C. to 1500°C.) ; but is very fluid when melted, and passes directly from the solid to the fluid condition, while white iron passes through a pasty condition before melting, and the same before solidification after fusion. Grey iron also expands at the moment of solidification after insinuating itself into the finest lines of the moulds used in the foundry, while white iron contracts under the same circumstances ; these qualities have led to the designation of No. 1, 2, and 3 grey iron as *foundry pigs*, while those below No. 3 in greyness are called grey and strong *forge pigs* respectively, since they are only available (except for special castings) for conversion into malleable iron, while No. 1, 2, 3 grey can be applied either to this purpose or to the requirements of the foundry.

In the Lancashire district the fifth grade or strong forge pig is designated by V, the lower grades being designated in the same manner as in the Cleveland district. In districts where hæmatites are smelted for the production of pig-iron applicable to the Bessemer process, two additional qualities have been introduced, called Nos. 1 and 2 Bessemer pig-irons respectively ; these, owing to their comparative immunity from phosphorus and sulphur, are particularly adapted to the requirements of the Bessemer process for the production of steel, and command a higher price in the market than the other class of pig-irons.

86. Mine and Cinder Pig.—Pig-iron smelted from ores (*mine*) alone, is known as *mine-pig*, whilst that smelted from puddling cinder and slags is termed *cinder-pig*.

87. Strength of Cast-Iron.—The strength of cast-iron to tensile, torsional, transverse, and crushing strains fluctuates between very wide limits ; and Fairbairn has shown that the strength increases after repeated melting up to the twelfth time, after which a repetition of the fusion decreases

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the strength. The presence of silicon in pig-iron also diminishes the strength. The experienced eye can often form a crude estimate of the amount of silicon in a pig-iron from the facility with which it breaks when dropped across the Λ block used in breaking the pigs; pig-iron made with hot-blast is also inferior in strength to cold-blast iron, probably from the more complete reduction of the silicon in the furnace at the high temperature produced by the hot-blast. The strongest pig-irons, then, are such as have been smelted with cold-blast from hæmatites containing but small proportions of silica, or from argillaceous ores.

From the published results of the experiments conducted at Woolwich Arsenal, it appears that the tensile strength of cast-iron varies from 4·85 tons to 14·00 tons per square inch, and its resistance to crushing from 22·54 tons to 58·42 tons per square inch of section, indicating the greatly superior strength of cast-iron under a crushing than under a tensile force.

88. Production of Pig-Iron.—The production of pig-iron from iron ore involves two stages; firstly, the preparation of the ore as received from the mine for the *blast-furnace* or *smelting* operation; and secondly, the reduction in the blast furnace of the metallic iron from its chemical combinations, together with its recarburization to pig-iron, and its separation from the earthy matters of the ore.

The first process, as practised in France, Belgium, Germany, and Sweden, includes two distinct operations, that of *washing* or *dressing* the ore for the concentration of its metalliferous portions, together with the subsequent roasting or calcination of this product, whereby water, carbonic acid, sulphur, and other volatilizable substances are eliminated under the influence of heat, or by the combined action of heat and air, leaving a more or less porous mass readily acted upon by the gases of the furnace. In England, however, the ores are not subjected to any preliminary dressing or mechanical treatment prior to *roasting* or *calcination*, and the dressing operations will not be further dwelt upon.

The production of white or grey cast-iron in the blast furnace is not perfectly under control; but for the production of white iron, mixtures of easily fusible ores are employed, so that the charge can be smelted more rapidly, thereby reducing to a

minimum the time of contact of the melted metal with the carbon of the fuel; also the proportion of ore to fuel in the charge is increased, and a greater burden of materials maintained; thus, other things being identical, the production of white iron is less costly than grey pig-iron. Owing to the lower temperature employed in its production, white iron does not contain so large a proportion of silicon as the grey pig, but often contains larger proportions of sulphur and phosphorus, and its carbon is almost wholly in the combined state.

89. Calcination.—In this country rich ores, as red hæmatites and magnetites, are not subjected to calcination, such not being necessary, water forming the chief volatilizable substance in this class of ores; in Sweden, however, all ores are subjected to a preliminary calcination before *smelting.* The hæmatites in Lancashire and the north are at once broken up into pieces about two inches square, and charged, along with *fluxes* and *fuel,* into the blast furnace, where the first effect is the expulsion of water from the ore contained in the upper portions of the furnace by the heat of the ascending gases. Other classes of ore are roasted or calcined in *heaps* or *kilns,* in which a careful regulation of the temperature is necessary to prevent the fusion of the ore into a more or less compact mass, or the partial reduction of the metal in carbonaceous ores, as blackband, etc. The effect of the roasting is to decompose to a great extent any *pyrites* present, with the volatilization of the sulphur and other volatile substances, together with the elimination of carbonic acid and water, and the conversion of *protoxide* and *carbonate* of iron into *peroxide,* thereby preventing the loss of iron from the formation of slags of silicate of iron, which occurs readily when silica and protoxide of iron are brought into contact in the furnace, such silicates being difficult of subsequent reduction. · The loss of weight in roasting amounts to 25 or 30 per cent. in Welsh argillaceous ores, to 50 per cent. in blackbands, to 6 per cent. in red hæmatites, and to about 12 per cent. in brown hæmatites.

The *roasting* or *calcination* in heaps or piles in the open air, or in kilns of various kinds, is conducted in much the same fashion as that described for charcoal burning; the heat being supplied partly from fuel mixed with the ore, and,

as in the case of blackband ironstone and other ores containing carbonaceous matters, is assisted by the combustion of such carbonaceous matters ; in other cases the kilns are heated by the waste gases of the blast furnace. Roasting in heaps is effected by making in the ground a bed of coal a few inches in thickness, on which is placed a depth of 10 or 12 inches of ironstone, alternating thus, coal and ore, until the pile reaches 4 or 5 feet in height; the process is then conducted by lighting the fire at the base, and damping with small ore those parts of the heap in which combustion appears to be too active or progressing too rapidly. A method adopted on the Continent consists in enclosing the ore and fuel for the roasting operation between vertical walls, in which openings are made along the sides at various heights for the regulation of the heat, the whole forming a kind of kiln.

The blackband ores of Scotland and Staffordshire usually contain sufficient bituminous or carbonaceous matter to effect the roasting, without any further addition of fuel or coaly matter beyond a single layer at the bottom for the commencement of the combustion.

In pyritic ores, the pyrites usually occur in plates, laminæ, or nodules along the planes of stratification of the ore, and Grundman* recommends that the blocks should be placed with these planes vertical in the roasting pile, so as to allow of the more ready escape of the sulphur.

In South Wales, the roasting or calcination is effected in massive kilns built of rough masonry, lined with fire-brick, the bottom of the kiln being formed of cast-iron plates. Arches built in the masonry allow of openings being made at the level of the floor for the extraction of the calcined or roasted ore from the bottom of the kiln, while the process is still going on in the upper zones of the kiln ; other openings above these serve for the admission of the necessary amount of air for carrying on the combustion and maintaining the heat required for the calcination. The horizontal section of such a kiln shows two parallel sides of masonry, connected at their two extremities by semicircles ; the kilns are much wider at the top than at the bottom. A kiln holding 70 tons of ore and fuel measures 20 feet in length, is 18 feet in

* Grundman. *d. Entschwefl der Eisenerze.*

height, and 2 feet in width at the bottom, increasing to 9 feet at the top. The operation is conducted by first lighting fires on the cast-iron floor, and covering these to the depth of a few inches with ore (ironstone) ; in a short time the mass is red hot, when a further layer of a mixture of ore, with about 5 per cent. of small coal, is placed over the heated mass, and so on, fresh layers or strata of the mixture being added as soon as the previous layer has attained to a red heat. By the time the kiln has been entirely filled, the layers in the bottom are ready for drawing, which is effected through the openings already mentioned in the base of the kiln. In this manner the charge of ore takes from three to four days for its calcination.

Kilns erected at the Newport Works, Middlesbrough, are cylindrical in section, built up of wrought-iron plates, and lined with fire-brick. The lower portion of the kiln tapers towards the base, and has openings all round the lower part for the admission of air and the withdrawal of the calcined *stone* or ore, which is directed to the openings by a central cone having its apex upwards. Each kiln has a capacity of 15,800 cubic feet, and holds about 630 tons of material.

In the self-coking blast furnace proposed by Mr. Ferrie of the Monkland Ironworks, the top is closed and surmounted by an arrangement for the coking of the fuel or calcination of the ore, heated by the combustion of the waste gases drawn from the top or throat of the blast furnace. Mr. Brown of the Shotts Iron Company has also introduced a furnace of this character, with a somewhat different arrangement for effecting the combustion and utilizing the heat of the blast-furnace gases, in an upper chamber or kiln surmounting the stack of the furnace. The Swedish calciner, heated by the waste gases of the blast furnace, consists of a cylindrical slightly conical shaft, formed of an exterior mass of ordinary brick-work lined in the interior with fire-brick, the whole supported by hoops or bands of wrought-iron. The outer wall is traversed by numerous horizontal openings for the escape of moisture, etc., and at the base are a series of openings through which the charge is withdrawn ; the gases from the blast furnace are introduced at the base of the kiln by 16 nozzles, and a little above them are the openings controlled

by dampers for the admission of the necessary air for the combustion of the gases, and above which again are a series of holes for the introduction of the bars used in breaking up the charge in cases of clotting from excessive heat or other cause.

The object of the roasting or calcination of iron ores being the expulsion of volatile ingredients, etc., leaving the ore as a porous mass, it is necessary that the temperature do not rise sufficiently high to clot or melt the ore, otherwise it becomes dense and impervious to the gases in the blast furnace. Ores containing silica, easily fusible silicates, or manganiferous compounds, have a tendency to clot; while calcareous ores, and compact ores rich in iron, bear a higher temperature, and a more prolonged calcination without matting or fusing together. Ores intended for the production of forge pig are more strongly calcined or roasted than if for foundry pig.

90. Weathering.—Very pyritous ores, such as are also accompanied by shales, instead of being calcined, are subject to a *weathering* action, in which the ore, placed in heaps, is exposed to the action of the weather for periods of three or four months, but varying with the amount of impurity, extending in some cases to three or four years; if containing much sulphur, the heap is frequently watered, so as to dissolve and remove the sulphates formed by the oxidation of the pyrites, etc.

91. Reduction or Smelting.—After calcination, the ore is broken into pieces more or less uniform in size; these pieces in the hæmatite districts are, as already stated, cubes of about 2 inches in diameter; in the Cleveland district, where the furnaces are larger and the fuel a hard coke, the pieces are larger, measuring from 4 inches to 6 inches; in Sweden, again, the furnaces are of a small description, and the pieces are not more than inch cubes. This breaking up of the ore after calcination is effected in special ore or stone crushers, or between rollers, appliances which have superseded the old stamps.

The blast furnace being at work, or, as it is technically called, *in blast*, it is kept filled to the top, or *throat*, by continually adding to the furnace the smelting mixture of *ore, fuel*, and

flux, as the charge works down; the supply of air or *blast,* under a pressure of from 2 to 5 lbs., in furnaces worked by coke, or of $1\frac{1}{2}$ to 2 lbs. in charcoal furnaces, being maintained through the twyers near the bottom of the furnace, except when the top is opened for the introduction of the charge, when the blast is shut off.

The oxygen of the air, injected through the twyers, meeting with incandescent fuel, is in a great measure immediately converted into *carbonic acid,* with the production of the maximum amount of heat, within a short distance of the twyers; the carbonic acid so produced, ascending towards the throat of the furnace, passes over a large mass of heated fuel, and is quickly reduced to *carbonic oxide;* thus,

$$CO_2 + C = 2CO,$$
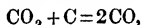
each volume of carbonic acid forming two volumes of carbonic oxide, with a corresponding reduction of temperature in the lower part of the boshes where this is effected. The carbonic oxide so produced, along with, perhaps, a smaller proportion derived from the deoxidation in the same manner of the carbonic acid expelled from the limestone used as a flux, then becomes the *principal* and *active* reducing agent of the blast furnace; ascending, it meets the mixture of heated ore and flux, which is descending towards the hearth; the porous oxide of iron, thoroughly heated and calcined while in the upper part of the furnace, is readily permeated by the gas, with the reduction of metallic iron; thus,

$$Fe_2O_3 + 3CO = 3CO_2 + 2Fe,$$
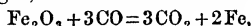
in addition, a smaller proportion of iron is probably reduced directly by the action of the fuel upon the ore at the high temperature existing in the furnace; thus,

$$2Fe_2O_3 + 3C = 4Fe + 3CO_2.$$
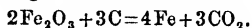
The iron thus reduced to the metallic state, in passing downwards towards the hearth of the furnace, comes into contact with a large amount of heated fuel, and combines with a varying amount of its carbon; a further carburization being probably effected by the decomposition of carbonic oxide, carburetted hydrogens, and possibly cyanogen compounds, by the reduced metal, with the production of the fusible compound of carbon and iron, with various impurities, constituting what

is known as pig-iron. It has been attempted to mark out, with some considerable accuracy, the various zones or limits within which the specific reactions occurring in the blast furnace are confined; but any such definite mapping must always be unsatisfactory, since the same furnace yields, at the same depth from the mouth or throat, very different products on different occasions. The cycle of operations by which the oxygen of the blast is converted into carbonic acid, with its almost immediate reduction to carbonic oxide, in its turn, again becoming carbonic acid by its reaction upon oxide of iron, is repeated as the gases ascend through the furnace, so long as the temperature remains sufficiently high to effect the decompositions ; the escaping gases, however, always contain a large proportion of carbonic oxide, which burns with its characteristic flame, though masked by the volume of yellow flame emitted at the mouth of the furnace if the gases are allowed to escape; or it forms a valuable source of heat, to be utilized for various purposes, as heating of the blast, or calcination of the ore, etc., if collected at the top of the furnace, as is now the usual practice in this country.

Fig. 11 is a diagram of the blast furnace divided into zones, as communicated in a paper by Mr. Lowthian Bell to the Institute of Civil Engineers,* showing the distribution of temperature and state of the materials at various depths from the throat of the furnace. The upper portion of the zone *a* is occupied by the raw ma-

Fig. 11.—ZONES OF BLAST FURNACE.

terials charged into the furnace, which are there being
heated by the ascending gases; towards its lower boundary
(and within 20 feet of the top of the furnace), the mass
is at a *dull red heat*, and the ore suffers reduction by
contact with carbonic oxide with the production of a
spongy metallic mass; the zone *b* is at a *red heat*, and
the limestone here suffers decomposition; *c* is at *full red-
ness*, and the descending spongy metal begins to absorb
carbon from contact with the fuel, which absorption con-
tinues through the next zone *d*, where the temperature has
attained to *bright redness*, and it is probably in this zone
that sulphur, phosphorus, silicon, etc., are to a large extent
reduced from the materials of the charge, and combine
with the pig-iron; in the boshes *e* the heat attains to *very
bright redness*, and the descending charge of spongy metal,
with slag-forming materials, undergo thorough fusion in
their descent through this zone; and in the crucible or
hearth *f*, where the heat is at its greatest intensity or
whiteness, the fused metal and slag separate, the fluid pig-
iron forming the lowest stratum, above which is the layer of
fluid slag.

The silica, clay, carbonate of lime, and the earthy matters
usually accompanying iron ores, as also the earthy matter
or ashes of the fuel, would descend along with the reduced
metal to the hearth of the furnace, and there remain mixed
with it, unless some other substance capable of combining
with these, with the production of a fusible compound or
slag, be introduced; such a substance is the flux employed,
usually limestone, the gangue of the ore being essentially
silica, or a silicious mineral, as clay, etc. The flux so added,
in addition to promoting the separation of the metal from
the *slag* or *cinder* in the hearth of the furnace, by combining
with any force silica in the charge, prevents also the loss
of iron, in the form of a basic silicate of iron, which would
otherwise occur, as the mixture passed through the zone of
most intense heat near the twyers; but if too much limestone
be added to flux the silica, the slag becomes too calcareous, is
fusible only with difficulty, and the metal separates imperfectly.
If the gangue of the ore be calcareous, the ores are mixed with
others containing silica or clay, as *forge cinder*, or the roasted

slag from the puddling furnace is introduced, though the iron produced from these latter is of an inferior kind, as will appear after consideration of the puddling process. By thus adding a suitable material to flux, or render the gangue fusible, the pig-iron separates from the slag in the hearth of the furnace, the latter rising to the top of the bath of molten metal, and protecting it from oxidation by the action of the blast. The slag is allowed to run away through an opening, to be presently described, and the metal is tapped out at intervals of twelve hours in South Staffordshire, or in the hæmatite districts of the north, every six hours; for this purpose, the blast is turned off, the tap hole broken open by an iron bar, and the metal run into a series of grooves, furrows, or channels, formed in the sand of the floor, near the furnace, or into cast-iron moulds; the furrows are of D section and arranged in parallel rows, the top ends of each row communicating with a common channel, along which the metal runs to supply the furrows in that row; this channel or *feeder* is hence known as the *sow*. In Sweden the metal is cast in rectangular plates in cast-iron moulds, the brand being cast on the under side of each plate or pig.

92. Blast Furnace.—The older blast furnaces were huge structures of stonework, shaped outside in the form of truncated four-sided pyramids, having walls of immense thickness, consisting of an outer structure of heavy masonry pierced by horizontal openings for the escape of moisture, inside of which was a second shell of brickwork set in cement, which, in its turn, enclosed the inner wall of fire-brick set in fire-clay, from 15 inches to 18 inches in thickness, and forming the inner wall or lining of the furnace; between each of these shells or casings of masonry was left a space which was filled with sand or slag, so as to allow of the necessary contraction and expansion of the several parts of the structure with the change of temperature. But during the past twenty years, one of the most marked features of blast furnace construction has been the reduction effected in the mass of materials employed in their erection; instead of the massive walls of brickwork or masonry, the shaft is now formed of an outer casing of iron plates, lined in the interior with but a few inches of brickwork, the bricks being carefully dressed, faced,

and made to the curve at each course; while this shaft, instead of resting on massive masonry pillars, is often carried upon cast-iron columns; at the same time the hearth of the furnace has been continually increasing in diameter. The hearth and boshes require to be of the most refractory material, being subjected alike to a most intense heat and to the corrosive action of the fluid slags; in Norway and Sweden these parts are often lined with a mixture of powdered quartz, fire-brick, and fire-clay well rammed in; but in England fire-brick is usually employed, the bottom of the hearth being formed of large blocks of sandstone or fire-brick built in the form of a flat inverted arch, forming a slight concavity upwards, thus preventing its being pressed upwards by the fluid metal getting beneath it.

The construction of the modern blast furnace varies much both as to shape, size, and the proportion of its parts, having regard to the nature of the ore to be smelted, of the fuel employed, whether charcoal or coke, whether hot or cold blast, and rapidity of driving, that is, the amount of air blown into the furnace in a given time; formerly the practice was to adopt open topped furnaces, but in England close topped furnaces, with an arrangement for taking off the gases, are now almost universally adopted.

The old type of furnace, still retained in Sweden, with only minor modifications of form, consisted of a vertical chamber or shaft open at the top and circular in section, formed as illustrated in No. 1 of fig. 10 by two truncated cones or funnels joined at their widest part or bases, which junction is known as the *boshes* of the furnaces, the part above the boshes being called the *stack;* while the *throat* or top of the *stack* is surmounted, when the furnace is open topped, by a sort of small chimney of brickwork called the *tunnel head*, supported by iron stays or boiler plates. Around the throat of the furnace is a gallery, forming a platform for the delivery of the charge, to be introduced into the furnace through openings in the tunnel head or some of the other arrangements subsequently described. The lower cone or sides of the boshes may be continued directly down to the base, or, as is more usual, its lower end is somewhat enlarged, constituting the *hearth* of the furnace; around the top of the hearth are openings, from

Taberg (Sweden).

Staffordshire.

Belgian.

Prussian.

Wigan.

French.

Glengarnock.

South Welsh
Anthracite.
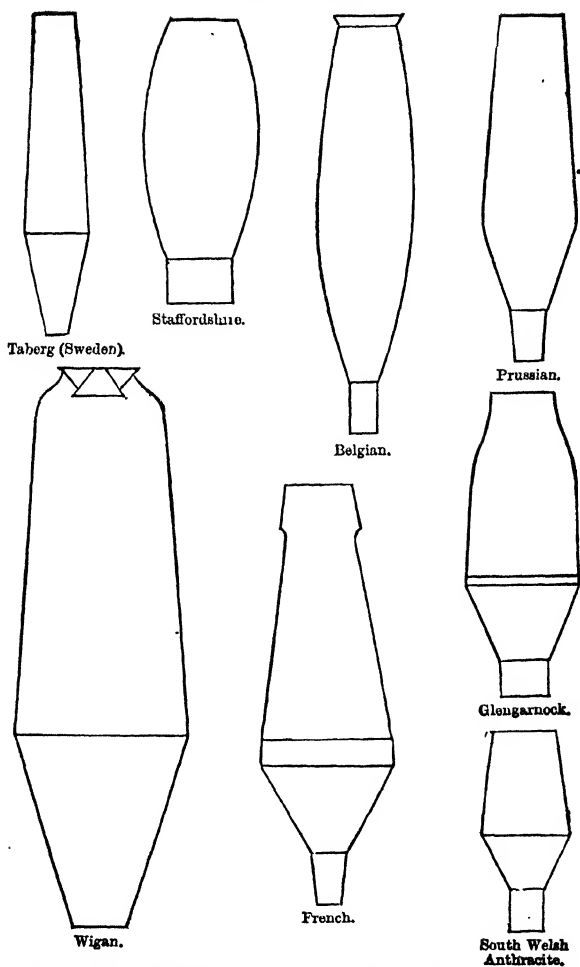
VARIETIES IN THE DIMENSIONS AND INTERNAL FORMS OF THE
BLAST FURNACE.

three to six in number, for the introduction of the *twyers* or pipes through which the blast is introduced; in many furnaces of Staffordshire, Wales, etc., the front or tapping side of the hearth is continued forward beyond the vertical line of the walls of the hearth proper, fig. 12; the cavity so formed, called the *fore-hearth*, is dammed up in front by some refractory material supported by a *dam-plate* of metal, and the arch over the opening so formed into the hearth or crucible of the furnace is called the *tymp arch*; on the under side of the tymp arch is placed a cast-iron box, inside of which is a curved wrought-iron pipe, through which flows a continuous stream of water, so as to keep it cool, and enable it better to sustain the great heat to which it is exposed, as also the corrosive action of the slags, which are continually flowing out beneath it. As the reduction or smelting proceeds, the slag and metal descend to the hearth, where the slag rises to the surface of the metal, and as the hearth fills runs over through a notch in the dam-plate called the *cinder notch*, and is received in trucks with movable sides called *cinder tubs*, which carry it at once to the cinder heap, or it is sometimes cast in blocks, and used for building purposes. In small furnaces this cinder notch is replaced by an inclined plane in front of the dam-plate, called a *cinder fall*, down which the slag is allowed to run and solidify, when it is broken up and removed by hand. A vertical notch 12 inches or 15 inches in length, stopped with sand or clay, is made in the side of the dam, forming the *tapping hole*, which can be readily opened by striking it with a pointed bar, and reclosed after the metal is tapped by the insertion of a clay stopping held on the end of a bar. The opening between the top of the dam and the tymp arch is closed during the working, with the exception of a small opening left for the escape of slag.

Instead of the sharp angles indicated above, as existing at the boshes and the top of the hearth, modern practice has adopted for the internal shape a more or less regular curve from the hearth to the throat of the furnace. All attempts to arrive at the best form of interior from theoretical considerations alone, have been attended with disappointment; it is, however, necessary that the furnace should contract from the

widest part or boshes to the hearth, since in this part the
charge is gradually decreasing in volume, due to the reduc-
tion and fusion of the metal; and also the diameter is so great
that for convenience in charging, and to allow of the proper
distribution of the charge, it is necessary that the mouth be
contracted. Fig. 12 is a vertical section of a blast furnace
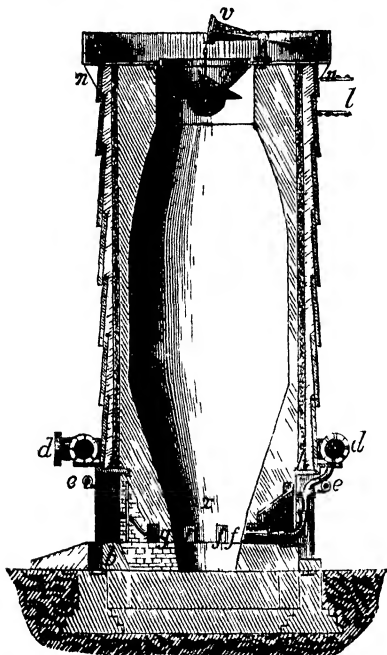
Fig. 12.—STAFFORDSHIRE BLAST FURNACE. Vertical Section
through the Tymp.

showing the general arrangement of the more recent Stafford-
shire and South Wales furnaces, in which the *stack* is cylin-
drical or slightly conical, coated externally with wrought-iron
plates riveted together, and fitted with the *cup and cone*
arrangement for introducing the charge of ore, flux, and fuel;

b is the *dam*, and *c* the cast-iron *dam-plate ; d* is the *blast-main*, from which pipes descend to each of the five *twyers* employed in this furnace, and *e* is a small *water main* supplying water to the water twyers *f, f, f ; g* is the *water tymp* with its coil of pipes, as already described, for keeping this part of the furnace cool, and so affording protection against the action of the fluid slags at the high temperature existing in this part of the furnace. The *stack* or cylindrical part of the furnace above the *hearth x*, is carried upon the iron ring *h, h*, supported upon cast-iron pillars ; and the waste gases are collected or drawn off through the opening *k* into the pipe *l*, which distributes them to the hot-blast stoves ; *m* is a gallery around the *throat* of the furnace, supported upon cast-iron brackets, *n, n*, from its sides, upon which is landed or received the materials to be introduced into the furnace. At the sides of the hearth are placed vertical racks, which serve as supports and points of resistance to the bars used in cleaning out the hearth of the furnace. The cup and cone arrangement, as well as the mechanism employed in raising and lowering the cone, are shown, and will be subsequently described.

In a blast furnace recently erected at Middlesbrough * (with the top closed by the cup and cone or bell arrangement, to be subsequently described), the foundation was of brickwork, resting on clay; on this a circular base of solid brickwork 7 feet in diameter was erected, having a stone curb, on which rested the columns, 18 feet 6 inches high, which carried the upper part of the furnace, the lower part being supported partly by a wrought-iron conical case, and partly by the brickwork and stanchions which surrounded the hearth. From the twyers upwards, the furnace was cased with wrought-iron plates, from $\frac{3}{8}$ to $\frac{1}{2}$ inch in thickness. The interior was lined with fire-brick lumps 5 inches thick, backed with ordinary fire-bricks. The lumps forming the bottom of the hearth, which was 4 feet 6 inches in thickness, consisted of two courses, set on edge and breaking joint. These lumps, as well as those forming the lining to within a short distance above the twyers, were chisel-dressed on both faces and joints, and made to the curve of the section

* Proceedings of the Institution of Civil Engineers.

at each course. The principal dimensions of the furnace are: diameter of hearth, 8 feet; diameter at the bosh, 28 feet; total height from hearth to platform, 85 feet; depth of hearth at twyers (four in number), 3 feet 6 inches; diameter of bell opening, 13 feet; and cubical capacity, 30,085 feet. The ore to be smelted in this furnace is the argillaceous iron-stone from the lias formation, yielding, after calcination, from 37 per cent. to 40 per cent. of metallic iron. The fuel is hard Durham coke, and the flux, principally mountain lime-stone. The furnace is worked with hot blast at a temperature of about 1100° F., with a pressure of $3\frac{3}{4}$ lbs., and the product is stated to be from 490 to 500 tons of pig-iron per week.

A well built blast furnace will often last five years without requiring to be blown out for repairs.

The blast furnaces employed at Barrow, Ulverstone, and other hæmatite districts of Lancashire and Cumberland, are of the *cupola* type, represented in fig. 13; those recently erected at Barrow - in - Furness being 62 feet in height, and 21 feet in diameter at the boshes, working
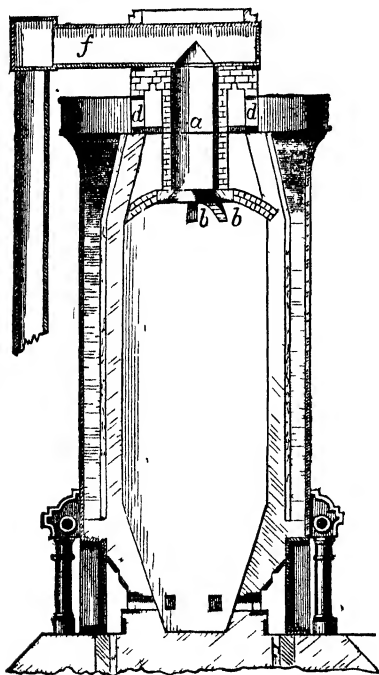
Fig. 13.—Sectional Elevation of Cupola Blast Furnace.

with closed tops; while those previously in use were a little less in capacity, and the waste gases were only partially collected by

a tube a suspended in the centre of the throat, and supported on six ribs of brickwork, as shown. The blast for these furnaces is heated to about 350°C. (662°F.) by passing through the hot blast stoves introduced by Mr Gjer, and is delivered through six 3-inch twyers, at a pressure of about 3 lbs. per square inch; such a furnace charged with *raw red hæmatite, limestone flux*, and using *coke* as fuel, affords a *make* of 400 tons of pig-iron per week. The stack of the furnace illustrated has an internal fire-brick lining 18 inches in thickness, between which and the outer casing of ordinary brick is a space filled by sand, the whole being enclosed in an outer casing of wrought-iron plates riveted together.

The *Blauofen* or charcoal blast furnaces of Styria differ from those adopted in this country, especially in the absence of a *fore-hearth*, and in the smallness of the throat. The furnace is formed of two truncated cones, the junction of their widest parts forming the boshes, and the front of the hearth is stopped by a stone, in which are openings for tapping out the metal and slag, either together or separately, the pig-iron and slag both collecting in the hearth until tapped out, an operation effected at short intervals. These furnaces smelt a spathic ore, poor in manganese, mixed with a brown hæmatite; the charge consisting of these ores, mixed with 10 per cent. of clay, passing from the throat to the hearth of the furnace in from $4\frac{1}{2}$ to 5 hours.

93. Charges of Furnaces, etc.—In the Siegen district, the furnaces producing speigeleisen, a charge of 45 cwt. consists of about 29 cwt. of roasted spathic ores, 7 cwt. of raw brown hæmatite, with 9 cwt. of raw limestone as the flux, and requires about 1 ton of coke for its reduction.

In South Staffordshire, the average charge consists of 48 cwt. of clay ironstone from the coal measures, 7 cwt. of red hæmatite, and 14 cwt. of silurian or carboniferous limestone per ton of pig-iron produced, with the consumption of about 3 tons of coal in hot blast furnaces, or the coke from 3 to $3\frac{1}{2}$ tons of coal when cold blast is employed.

The average mixture for the production of a ton of pig-iron in the Cleveland district consists* of 70 cwt. of the argillaceous carbonate of iron, known as the Cleveland iron-

stone, with 15 cwt. of limestone and 26 cwt. of coke, the charge requiring about 36 hours for its descent to the furnace hearth.

At Dowlais, and other works of South Wales, the descent of the charge from the mouth to the hearth of the furnace occupies from 35 to 40 hours; while in the Scotch furnaces, smelting blackband ironstone, in certain cases, the charge does not reach the furnace hearth before $2\frac{1}{2}$ or 3 days after charging.

94. Furnace Tops.—For the purpose of collecting more or less perfectly the waste gases escaping from the top of the blast furnace, in order to utilise or absorb the heat due to their high temperature, as also that which they are capable of generating by their perfect combustion, in the heating of the blast, coking coal, raising steam, etc., various methods have been adopted for both open, closed, and partially closed topped furnaces.

In reference to open topped furnaces, the simplest and most durable form is a method adopted for charcoal furnaces in the Upper Hartz and elsewhere, in which an annular space is formed in the masonry of the upper end of the stack of the furnace, communicating with the interior of the furnace beneath the surface of the charge by a number of openings or channels inclining upwards to prevent the lodgment of the charge in them ; a large pipe opens into the annular space, and is connected with a high stack for the production of the necessary draught to draw off the gases through this channel. In another arrangement a wrought-iron cylinder, of from 4 to 7 feet in length, is suspended in the mouth of the furnace, or a brick tube is built in the throat, and supported at its base upon arms of brickwork from the sides of the furnace, thus leaving a space between the outside circumference of the tube and the inner surface or lining of the furnace, in which space the gases accumulate and are led off by a pipe opening into it, connected as before with a stack giving the required draught for exhausting or drawing the gases in this direction. Instead of diminishing the furnace mouth by the introduction of this tube, sometimes the top of the furnace is increased in size, so as to receive the tube, when the inside of the cylinder is made of the same diameter

as the top of the furnace, a space being left between its outer periphery and the mass of brickwork of the furnace, which space is connected with a tube and stack for taking off the gases. In these arrangements the gases are withdrawn from the *circumference* of the furnace, and only a portion of them are collected, a certain volume escaping and burning at the open mouth of the furnace.

In the cupola blast furnaces used in smelting hæmatite, illustrated in fig. 13, p. 80, the top of the furnace is only partially closed, and the gases, which are only partially withdrawn, are taken from the *centre* of the throat of the furnace, for which purpose a tube *a* is inserted in the middle of the throat, resting at its lower end on arched ribs of brickwork *bb* springing from the lining of the furnace. An annulus is thus formed around the tube between it and the upper course of masonry or *ring-wall* of the furnace, which space communicates by a number of openings *dd* with the gallery or platform at which the charging material is delivered, and through which the charge is introduced into the furnace. The tube *a* communicates with the cross tube *f*, by which the gases are conducted to the boilers for raising steam, to which purpose they are here wholly applied. The withdrawal of the gases through *a* is assisted by an exhausting fan.

Of arrangements which necessitate the *closure of the throat* of the furnace, and in which the whole of the gases are collected, the most prevalent is some form of the *cup and cone* arrangement, illustrated in fig. 12, page 78, consisting of a cast-iron cup, funnel, or frustum of a cone *q*, fixed to the top of the furnace, the lower opening being about one-half of the diameter of the furnace at that point. Beneath the cup is a cast-iron cone *s*, suspended from its apex by a chain or other attachment from a counterpoised lever *v*, which can be elevated or depressed about a fixed centre by gearing, or a system of levers acting on its free end, whereby the cone *s* can be raised or lowered; *k* is a pipe opening into the furnace, leading the gases from the throat of the furnace to the hot blast stoves, boilers, etc., where they are consumed, and their calorific power utilised. This method of withdrawing the gases affords also a convenient method of charging the furnace, the charge of ore, fuel, and fluxes being placed

in the cavity or hopper q formed by the cup arrangement whilst the cone is raised against its seat, and is allowed to fall at the desired period by lowering the cone s, its form assisting also in the better distribution of the charge over the surface of the materials already in the furnace, the larger pieces of fuel, etc., rolling towards the centre, while the smaller portions remain at the circumference. In this arrangement the mouth of the furnace is only opened to the atmosphere during the short interval in which the cone s is lowered for the introduction of the charging materials.

In order to economise the space required in the top of the furnace for the downward movement of the cone s in charging the furnace, it has been proposed to fix s in the throat of the furnace, and substitute for the cup q a movable cylinder of cast-iron, which could be drawn upwards so as to allow the charge to fall into the furnace; but arrangements of this class do not perform the part of distributor of the charge as efficiently as the cup and cone arrangement, and have accordingly been discontinued.

In Langen's arrangement, erected at Hörde and Siegburg, in Prussia, the mechanism is wholly external to the furnace, and, while closing the mouth of the furnace, withdraws the gases from the *centre* of the throat of the furnace, instead of from the sides, as in the previously described arrangements. This apparatus consists of a bell suspended above the throat of the furnace, from the extremity of a lever, by which it can be raised or lowered, for the introduction of the furnace charge after the manner of the cylinder already mentioned, the bell sliding telescopically on the outside of the vertical gas tube, the several joints being kept tight by water, which requires to be added at intervals to supply the loss by evaporation, and the top of the tube is supplied with a safety valve to prevent explosions.

95. Blast-main, Twyers, etc.—The blast from the blowing engines is distributed around the blast furnace in a pipe d, fig. 12, p. 78, called the *blast-main*, situate in the more modern furnaces at some distance above the level of the ground, and supported from the columns or pillars carrying the stack of the furnace. In the older form of furnace, where the stack is carried upon four huge columns of masonry, an

arched annulus was built in the base of the masonry for the reception of this pipe or blast-main. A pipe called the *goose-neck* passes vertically from the blast-main opposite each twyer opening, where it is connected by an elbow-piece with a horizontal pipe, to the end of which is attached the *blast nozzle* or *blowpipe*, which is received by the twyer proper. The bend or elbow usually contains an opening closed by a glass or mica plate, to enable the workman to see into the hearth of the furnace, the bright spot thus seen being called the furnace *eye*.

The blast is controlled by a stop valve on the main near the hot blast stove, or blowing engines, in addition to which each twyer has its own valve for the regulation of the blast. In cold blast furnaces the twyer is made of iron or copper, into which the blowpipe is loosely inserted or connected to it by a flexible leather tube; but in hot blast furnaces, owing to the increased pressure and higher temperature employed, these connections are inadmissible. The twyer, as represented in section in the accompanying figure, known as the Staffordshire twyer, consists of a hollow truncated cone of wrought-iron, with double walls, leaving a clear space between the two for the circulation of a current of cold water, introduced and withdrawn by the two pipes shown. In the Scotch twyer, a spiral of wrought-iron is enclosed in a cast-iron casing, through which the water circulates.

Fig. 14 —HOT BLAST TWYER.

Bronze and an alloy containing phosphorus, known as *phosphor bronze*, have been used for twyers with reported success, as not being so readily acted upon by the masses of metal which occasionally attach themselves to the twyers.

The horizontal pipe connecting the water twyers with the goose-neck, or vertical pipe from the blast-main, consists of two portions: the extremity or *blowpipe* end, formed of sheet-iron, is inserted loosely in the conical twyer, the space around it being plugged up with clay; its other end is connected by a ball and socket joint with a telescopic pipe, the latter actuated by a screw, or rack and pinion, whereby the

blowpipe can be inserted or withdrawn readily for the removal of a leaky twyer, or other cause; while the ball and socket joint allows of an adjustment of the direction of the blast, according as it is desirable to direct it upwards, downwards, horizontal, or in a lateral direction. It is often desirable, for instance, when the produce is forge pig, to direct the blast horizontally, or slightly downwards, whereby a partial decarburization of the melted pig metal may be affected, attended also with the partial removal of the sulphur, phosphorus, arsenic, etc., from the pig-iron. And when smelting refractory ores, or producing grey pig-iron, an upward inclination of the twyer is found advantageous.

The number (rarely exceeding seven) and size of the twyers depends upon the capacity of the furnace and the amount of blast to be introduced, as required for the different classes of ore treated and the iron obtained. Too much blast is attended with an increased consumption of fuel per ton of metal produced, also the reduction is effected too rapidly, insufficient time being allowed for the recarburization of the reduced iron; also the slags are cooled, and more or less solidified. On the other hand, an insufficiency of blast is attended with a loss of heat in the furnace, and the *make* (yield) of iron is diminished. The production of carbonic acid, with its attendant maximum of heat, extends but a short distance from the vicinity of the twyers, and, therefore, by arranging the twyers uniformly around the furnace, the combustion and heat generated are more perfectly distributed over the hearth than by passing the whole of the blast through one or two points. If one twyer only be used, it is the practice to place it in one side of the furnace, a little nearer the back than the front, the tymp being considered the front side; where two are employed, as in small charcoal furnaces, they are placed in the sides opposite each other; and if a third be added, it is placed at the back opposite the tymp; while, if a larger number are required, they are either placed in groups in each of the twyer arches, as two in the back wall, with one at each side, or two or more at each side, with one or more at the back; or as in cupola, and other furnaces, with circular hearths, the twyers are usually distributed at equal distances around the circumference.

96. Lifts.—For the purpose of raising the materials of the charge to the furnace mouth, except in hilly countries, where the mine is above the level of the summit of the furnace, and the materials can be run directly from the mine to the charging gallery, *lifts* or elevators of various types are employed. Amongst the older forms still employed is the inclined plane, fig. 15, an arrangement consisting of an inclined tramway between the ground and the top of the furnace, inclined to the horizontal at an angle of 25° or 30°;
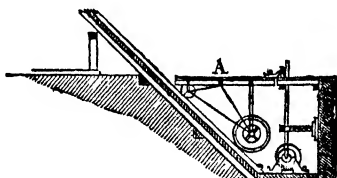
FIG. 15.—INCLINED PLANE, for elevating the charge to the furnace mouth.

it is formed of a pair of girders, braced together, and supported by one or more pillars, or upon trestle work, between the foot of the plane and the platform at the mouth of the furnace; on this incline is placed a platform carriage, A, triangular in vertical elevation, with two pairs of wheels of unequal size, as shown. The platform or table of the carriage is always horizontal as it moves up and down the inclines, and when at the foot of the plane, the table is level with the surface, so that the barrows can be run directly on to it, the table being large enough to hold four or more of the wheel-barrows employed for charging, also, when the carriage arrives at the top of the incline, the table is then level with the charging platform of the furnace, and the barrows can be moved directly off the carriage on to the platform or gallery. At the Barrow Iron Works, two of these inclines are placed side by side, the carriages being connected together by a chain passing round a drum, so that as the one ascends, the other is descending, the necessary power being obtained from a small engine on the surface driving the winding apparatus. At these works, two planes are sufficient for the supply of

seven furnaces, or for raising about 8000 tons of ore, and other materials per week.

The inclined planes, Jacob's ladder, and other forms of lift, have generally given place to some form of vertical lift, actuated either by steam, compressed air, or hydraulic pressure. When steam is employed direct, the material to be raised is placed in a cage, or placed on a platform, moving between vertical guides, and connected with a piston actuated by the steam pressure. Of hydraulic lifts, amongst the most perfect are those constructed upon Sir W. Armstrong's principle, in which the platform is connected by a chain passing over a system of pulleys before being attached to the ram, which is actuated by the hydraulic pressure, whereby, according to the multiplication of the lengths of chain by the system of pulleys employed, the table is raised to a more or less considerable distance for a short movement of the ram ; in this manner a movement of 5 or 6 feet in the ram, actuated by hydraulic pressure from any source, communicates to the lift an elevation of 30 or 40 feet, or more.

Of the numerous pneumatic lifts, the one most extensively adopted in the more modern of the Cleveland furnaces is that of Mr. Gjers, in which a large cast-iron piston or ram, to which the table or lift is connected by means of wire ropes passing over large pulleys, and attached to each corner of the lift, works in a cylinder, some 36 inches in diameter. The weight of the piston is adjusted so as to exceed the weight of the empty platform by an amount, say, of one ton, while the platform, when loaded, is heaver than the piston by the same amount; hence, on applying beneath the piston a pressure of 3 or 4 lbs. above the atmosphere, it rises, and the table is brought down, while a similar exhaustion or vacuum produced beneath the piston causes it to descend, and the loaded platform to ascend. The necessary pneumatic pressure or vacuum is obtained from a small engine working pumps, which, by altering the position of a reversing lever, act either as exhausting or forcing pumps.

97. Blowing Engines.—The engines for supplying the necessary air to blast furnaces are of numerous types, some of which are of considerable dimensions, requiring to discharge as much as from 50,000 to 60,000 cubic feet of air per

minute, under a pressure of about $3\frac{1}{2}$ lbs. per square inch. For this purpose, some form of *cylinder* blowing engine has been generally adopted in lieu of the fans, bellows, blowing chests, etc., formerly applied. Various arrangements of the steam and blast cylinders have been devised, according as the engines are horizontal or vertical acting, or beam engines. The blowing cylinder consists of a cast-iron cylinder fitted usually with a solid piston, receiving a reciprocating motion from the engine shaft, whereby, by suitable valves arranged in the cylinder covers at each end, the piston alternately draws into and expels the air, at both ends of the cylinder, at each stroke of the engine. The arrangement of valves allowing of this action is very varied; in many cases, as above cited, the cylinder covers contain india-rubber, leather, or other valves, allowing of the required action; while in other types the valves are external to the cylinder itself, and are worked by an independent connecting rod, opening and closing alternately each end of the cylinder to the atmosphere and the blast-main respectively.

To avoid the fluctuations, irregularities, and intermittent action of the blast, that would occur from an injection of the blast direct from the engine to the furnace, a *regulator* is inserted in the course of the main, between the engine and the furnaces; this is merely a reservoir of iron, or occasionally of masonry lined with cement, of a capacity equal to from 20 to 50 times the volume of blast delivered per second, and provided with a manhole and safety valve. In this manner the blast is delivered in a continuous stream. If the main or pipes between the engine and the furnaces are of considerable length, the regulator becomes unnecessary, the volume of air contained in the pipes serving the same purpose.

98. Rachette Furnace. — The Rachette furnace has a shaft *a* about 30 feet in height, rectangular (oblong) in all horizontal sections, and gradually increasing in width from the hearth to the mouth, which is about two and a half times the width of the hearth; the twyers, from twelve to sixteen in number, supplied from the blast-mains *f, f* are arranged in two rows in the long sides of the furnace, not opposite each

other, but so that the nozzles on the one side direct the blast against the space between the twyers of the opposite side, and so distribute the blast more uniformly over the area of the hearth; or, instead of separate twyers, one long twyer, with a horizontal slit in the direction of its length, distributing the blast in one continuous sheet of air, has been tried.
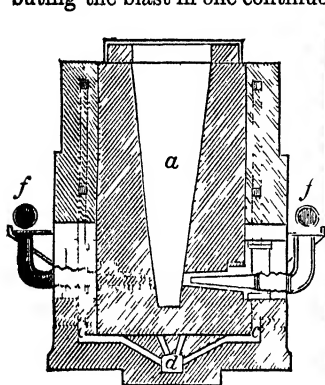
Fig. 16 —Vertical Section of Rachette Furnace.
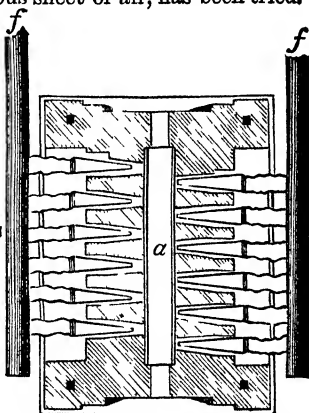
Fig. 17.—Plan of Rachette Furnace.

The two ends or fore-hearths are exactly alike, allowing the metal and slag to be tapped from either end. In the walls are left a number of channels c,c communicating with one another, and with similar passages and a chamber d placed in the masonry beneath the hearth; these passages have a threefold object: they serve to heat the masonry more quickly and uniformly, when the furnace is first lighted or *blown-in,* by circulating, through the walls of the furnace, the gases from a fire made in the chamber d; and during the working of the furnace cold air circulates through them, cooling the mass of masonry, especially of the hearth, and lessening the transmission of heat from the furnace to the exterior; lastly, they lessen the cost of the furnace by reducing the quantity of materials employed in its erection. An economy in fuel is claimed for this furnace, due to the longer time during which the smelting materials are exposed to the

ascending gases, due to the diminished velocity of the latter from the increasing section of the furnace towards the mouth, with a consequent reduction of the temperature and diminution in the loss of heat carried away in the escaping gases.

In the Ural districts of Russia, where these furnaces were first erected, they were worked with cold blast and charcoal fuel, smelting magnetic iron ores, when the produce of grey pig-iron was 30 tons per day of twenty-four hours.

99. Hot Blast.—The use of the hot blast, patented by Neilson in 1828, was first used in the Clyde Iron Works, and its use at the Blythe Iron Works was attended, in 1831, by the substitution of raw coal for coke, and so rapid was its general adoption that, with one exception, it was in universal application throughout Scotland in the year 1835.

The temperature to which the blast is raised depends upon the *nature* and *quality* of the fuel and ore employed, together with the kind of pig-iron to be produced. Charcoal, as being less dense, and more readily combustible, does not require the blast to be heated so high as when coke is the fuel; accordingly, in charcoal furnaces, the blast is usually heated from 100°C. to 300°C. (212°F. to 572° F.), while in coal and coke furnaces the temperature employed rises as high as 600°C., (about 1100°F.). The temperatures most generally in use range from 315°C. to 426°C. (600°F. to 800°F.).

With the use of the hot blast, the combustion of the fuel is effected much lower down in the furnace, with a considerable increase of the temperature in the vicinity of the twyers as compared with the same furnace working under cold blast; for while the injection of cold air is attended with a very considerable absorption of heat in the vicinity of the twyers, due to its great increase in volume by the heat of the furnace, the hot blast enters already expanded to the degree corresponding to its increased temperature; and this, together with the more rapid combustion of the fuel, effected by the heated blast, with the conversion of its carbon into carbonic acid, causes the calorific intensity of this zone to be much increased, which increase in the temperature first necessitated the use of water twyers for hot blast furnaces. The effect of the introduction of the hot blast is a very

considerable economy in the item of fuel. Percy states that at the Clyde Iron Works in 1829, when cold blast was used, the average consumption of coal used as coke was 8 tons 1 cwt. 1 qr. per ton of pig-iron produced, while in 1833, at the same works, when using hot blast, heated to 300°F. (149°C.), the average consumption of coal was reduced to 5 tons 3 cwt. 1 qr. per ton. The same author gives the estimated amount of charcoal used in the Swedish furnaces employing blast heated to 350°C. (662°F.), producing grey iron from lake and bog ores, to be ·67 per cent. of that required for similar furnaces working with cold blast; while, if producing mottled iron from mountain ores, with blast heated to 200°C. (392°F.), the saving is 20 per cent. in the fuel, compared with cold blast.

The advantages of the hot blast, then, are chiefly the *saving* in fuel, with the increased *make* of the furnace. The former economy arising, as already noted, from the higher temperature of the zone near the twyers, consequent upon the more rapid combustion of the fuel when burnt by heated in lieu of cold air, whereby the zone of active combustion or greatest heat is brought to a lower level in the furnace, attended with the reduction of the metal at a greater depth from the mouth than occurs under cold blast, and in this manner allowing of the use of raw coal instead of coke ; while from the enlarged hearth, with a better distribution of the heat over it, and the *heavier burdens* carried by hot blast furnaces, an increased *make* of iron is ensured. With the use of hot blast, the slags require to be more basic than in cold blast furnaces for the production of the same pig-iron, since, owing to the increased temperature produced by the hot blast, an increased amount of silicon will be reduced and pass into the pig-iron, with a deterioration of its quality as a foundry pig, unless its reduction be to a certain extent prevented by the addition to the charge of a larger proportion of lime, thereby rendering the slag more basic.

100. Blast Ovens, etc.—The apparatus employed for heating the blast, known as *hot blast ovens* or *stoves*, consist usually of a series of tubes of various forms, connected at one extremity with the cold air, and at the other with the hot blast-main ; they are arranged in a chamber of fire-brick,

and heated externally, either by an independent fire made beneath, or more generally by the combustion of the waste gases collected from the mouth of the blast furnaces, which are burned in these stoves, the flame and gases playing around the outside of the pipes before escaping to the atmosphere. The stoves heated by the last method are more durable than if heated by coal burnt on an independent grate. More recent are the stoves of Mr. Cowper and Mr. Whitwell, erected upon the regenerator principle of Mr. Siemens, in the use of which a large saving in fuel is effected.

The older form of stove consisted of a chamber containing a series of arched pipes of cast-iron, the feet of which were received in sockets connected with two mains placed along the sides of the chamber in the direction of its length, one of which was the cold and the other the hot blast-main. The arched pipes were at first made circular in section, but to increase their heating surface, oval or elliptical and square sections have since been employed. This stove, when heated by fuel direct, has an oblong fireplace along its whole length; but, as is now more usual, the gases from the blast furnace are introduced at one end, and air is admitted for their combustion through the bars of a grate placed at the same end. From eight to twelve pipes are thus placed in one chamber, which has a partition across the middle of its length, reaching nearly to the roof, and thus dividing the larger chamber into two shorter ones, so that the gases or flame, after circulating around the pipes in the one, pass over into the other, and heat the pipes contained therein before escaping to the chimney or stack. To obtain a better circulation of the air through the pipes, *stops* have been introduced into the mains, so that the blast ascends the arched tube from one main and descends to the opposite one; then returns back to the first main by the next pipe, and so on, so that the blast, before making its exit, circulates from one side of the oven to the other repeatedly in its course through the stove. In this form of stove the unequal expansion of the pipes, with their extremities fixed to the mains, leads to very frequent breakages, to obviate which one of the mains has been placed on rollers, allowing it an inward or an outward motion, as required by the expansion of the arched pipes.

In what is known as the *pistol pipe* modification (fig. 18), from a supposed resemblance in the form of the pipe to the shape of a pistol, the pipes *a* are arranged along the two sides of the median line or fireplace *b*, if the stove be heated by such ; the pipes of the two sides are not, however, connected by an arch, as in the last case, but the closed end of each pipe is turned slightly over and may rest against the opposite pipe, which thus support each other without being directly connected. Each pipe is divided by a septum or partition,
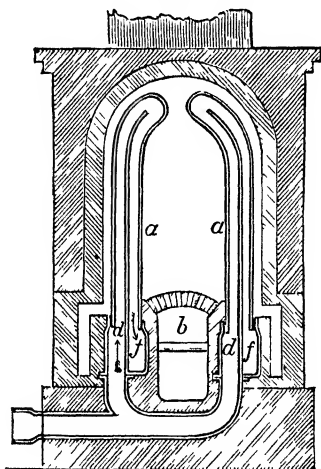
Fig. 18.—PISTOL-PIPE HOT BLAST STOVE.

reaching nearly to the closed end, and connected at its foot with a corresponding division in the main *c*, so that the cold blast from the intake *d, d* ascends the pipe and returns down the same pipe, but on the opposite side of the septum, as indicated by the direction of the arrows, to the exit side *f* of the main, which is connected with the furnace. This form of stove is used in Scotland, Cleveland, and other districts of England, as also in France and Germany.

In the round and oval ovens used in Lancashire and Staffordshire, the two mains, running the length of the stove

in the previous cases, are replaced by a cast-iron circular or oval ring, trapezoidal in section, and divided by a partition into two compartments, or an inner and an outer annulus, one of which serves as the cold and the other as the hot blast-main; the two pipes or channels so formed receive the lower ends of the vertical heating pipes, which are placed close together in pairs all round the stove, the upper extremity of each pair being joined by a short horizontal pipe; the fireplace is placed in the centre, the flame and products of combustion making their exit through flues in the dome surmounting the heating chamber or oven.
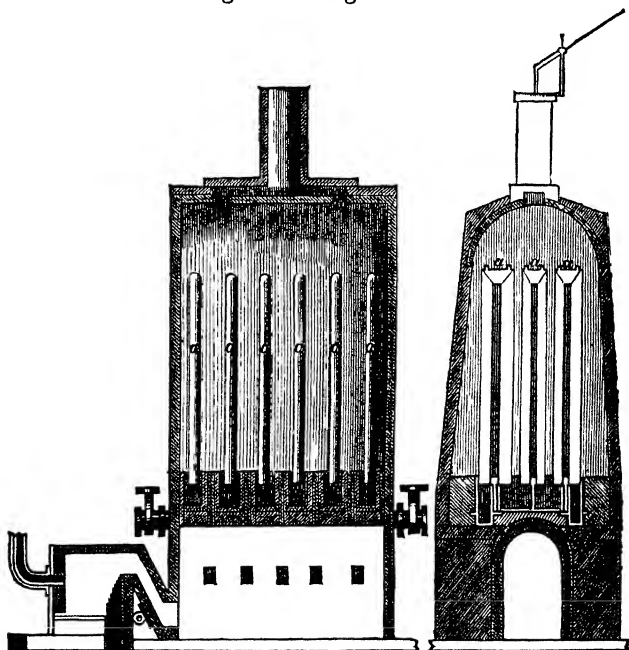
Fig. 19.—*Longitudinal Vertical Section.* Fig. 20.—*Transverse Section.*
HOT BLAST STOVE.

Other stoves in use in Lancashire, Staffordshire, etc., are

rectangular in form (figs. 19 and 20), and have two mains. running along the sides for the length of the stove, which serve as inlet for the cold air and outlet for the heated blast respectively ; these pipes or channels receive the lower end of one limb of each of the vertical heating pipes a, a, of which there are six rows of three pipes each, in each stove, and the cold air entering at one end of the oven ascends one limb and descends through the other limb of each of these pipes before it passes out of the stove to the hot blast-main. The stove is heated as before, either by its own fire or by the gases of the blast furnace, introduced into a chamber beneath the pipes, and burnt in the space surrounding them, the flame and products of combustion making their exit through flues b, b, in the dome surmounting the heating chamber or oven.

The loss and difficulties arising from the fracture, rapid corrosion, and oxidation of the iron pipes when very high temperatures are employed, have led to the introduction of stoves on the Siemens' "regenerator" principle; the mass of brickwork forming the regenerator or stove is heated either by its own direct fire, or by the sensible heat, as also the heat from the combustion of the waste gases of the blast furnace.

101. Cowper's Stoves.—The hot-blast stove introduced by Mr. Cowper acts upon the principle of the Siemens' regenerator, in which fire-brick heating surfaces are substituted for the cast-iron tubes, detailed in the previously described stoves, permitting of a much higher temperature being imparted to the blast than is practicable in stoves of which cast-iron is the heating surface, and in the use of which a correspondingly large increase occurs in the yield of the blast furnace. In the earlier forms of this stove, introduced at Ormesby, near Middlesbrough, the fire-brick chambers were, heated by a fire maintained below them; but the more recent ones are heated by the combustion of the waste gases of the blast furnace. For heating the blast continuously, a pair of stoves is necessary, the blast being turned alternately at intervals of about one and a half hours through each. As applied for utilizing the blast furnace gases, the stoves consist of cylindrical chambers of fire-brick, closed at the top, and

cased with wrought-iron slabs; a vertical shaft, formed in the middle of the stove, reaches almost to the roof; around this, and between it and the walls of the stove, is built a considerable mass of fire-brick, arranged so as to leave rectangular spaces between and amongst the bricks, for the passage of the gases or cold air to be heated; the central shaft communicates at the bottom with channels, controlled by suitable valves connected with pipes for the introduction of the furnace gases and air for their combustion, and with a flue from the stack for producing the necessary draught; or, closing these, communication can be opened between it and the exit pipe, or pipes, leading the heated air to the blast furnace. In this manner the combustion of the gases is effected at the top of the stove, and the flame, with the heated gases, is drawn down through the channels amongst the bricks, and escapes to the stack at a comparatively low temperature, while the mass of brickwork, in from one and a half to two hours, will have attained a uniform strong red heat; the gases are now turned off, and communication with the chimney closed. At the same time the valves are opened, by which cold air is drawn in at the bottom and passes upwards from the colder to the hotter part of the stove, reabsorbing the heat previously imparted to the fire-brick, the temperature of the air in this manner being raised to 700° C. or 800° C. before being driven into the blast furnace. Meanwhile, the other stove has been heated in the manner first described, and, after one and a half hours, the course of the gas is again reversed, and the first chamber is reheated while the second chamber is heating the blast, and so on. A practical difficulty in the use of this stove arises from the deposition of tarry matters, dust, etc., amongst the bricks, and the sudden change in temperature when the direction of the current is reversed is also objectionable.

102. Whitwell's Stove.—To overcome the difficulty arising from the deposition of dust and solid matters passing over with the blast furnace gases, in the spaces between the bricks of Cowper's stove, Mr. Whitwell has substituted, for the arrangement of bricks in the Cowper stove, an arrangement of vertical cells or chambers, formed by vertical fire-brick walls, contained in a circular chamber, which thus form flues

through which the flame and heated gases, or cold air, are made to circulate in a similar manner to that last described, the arrangement allowing of the removal of the deposit of flue dust as it accumulates, by the insertion of suitable iron scrapers.

103. Composition of the Blast-Furnace Gases.—The composition of the gases present in the blast furnace has been investigated at different times by Bunsen, Ebelmen, Scheerer, Playfair, Tunner, Schafhaütl, Rinman, and others. The gases which escape from the furnace mouth are not essentially different, whether hot or cold blast is employed, except that in the case of hot blast using raw coal as the fuel, the gases will contain traces of volatile products arising from the distillation of the coal in the upper zones of the furnace. The following table, collected from the work of Dr. Percy, gives the composition of the waste gases from the tops of three blast furnaces, in which raw coal, coke, and charcoal, respectively, are the fuels employed, all employing limestone as the flux, while the first is smelting calcined argillaceous ores, the other two smelting brown hæmatites, and in the first the blast is heated to 626°F., in the second to 212° F., and in the third cold blast is employed.

COMPOSITION BY VOLUME OF BLAST-FURNACE GASES.

FURNACES.	Nitrogen.	Carbonic Acid.	Carbonic Oxide.	Marsh Gas.	Hydrogen.	Olefiant Gas.	Analyst.
1. Alfreton, England,	55·35	7·77	25·97	3·75	6·73	0·43	Bunsen and Playfair.
2. Seraing, Belgium,	57·06	11·39	28·61	0·20	2·74	...	Ebelmen.
3. Clerval, France,	57·79	12·88	23·51	...	5·82	...	Do.

From these figures it appears that the gases have essentially the same composition in the different cases; the nitrogen derived from the air, introduced as blast, passing through the furnace unaltered, and forming more than one-half of the volume of the gases, while carbonic oxide forms 25 per cent. of their volume; the other combustible gases consisting of hydrogen, marsh gas, and olefiant gas, all deriving their

hydrogen, chiefly from the decomposition of the water vapour carried in by the blast; in addition to these there are small quantities of cyanogen.

The following table, giving the composition of the gases at various depths below the mouth of the furnace, as taken from the Alfreton furnace (which is 40 feet in height, worked with blast, heated to 330°C. (626°F.), under a pressure of 6·75 inches of mercury, and smelting materials as above), shows the proportion of carbonic acid to carbonic oxide to be continually diminishing with the increase in depth below the mouth; and in the upper portion of the hearth (fifth column), the gases consist almost wholly of nitrogen and carbonic oxide, with a small proportion of hydrogen. Charcoal furnaces, owing to the light and readily combustible nature of the fuel, yield carbonic oxide even at the lowest level, and a few inches above the twyers carbonic acid is almost absent, while the amount of carbonic acid rapidly increases in the upper portion of the furnace charge.

ALFRETON FURNACE.	Depth in English feet below the mouth.				
	8	14	20	24	34
Nitrogen	54·77	50·95	60·46	56·75	58·05
Carbonic acid	9·42	9·10	10·83	10·08	0·00
Carbonic oxide..................	20·24	19·32	19·48	25·19	37·43
Marsh gas........................	8·23	6·64	4·40	2·33	0·00
Hydrogen	6·49	12·42	4·83	5·65	3·18
Olefiant gas	0·85	1·57	...	...	...
Cyanogen	...	...	...	Trace.	1·34

The gases escaping or collected at the mouth of the blast furnace carry over with them considerable quantities of a fine dust, consisting largely of *silica, peroxide of iron, alumina,* and *lime,* with smaller proportions of peroxide of manganese, magnesia, potash, soda, sulphate and phosphate of lime; and in smelting iron ores containing oxide of zinc, considerable quantities of zinc fume or oxide of zinc collects in the pipes or culverts through which the gases pass, requiring removal at intervals, when the oxide of zinc so obtained is sold for the extraction of metallic zinc.

104. Slags.—Blast-furnace slags differ very widely in

physical characters and chemical composition, according to the character of ore and fuel employed, the quality of iron produced, whether light or heavy burdens are being worked, and according as hot or cold blast is employed. Slags accordingly occur varying in colour from almost white or grey, through all shades of brown, yellow, green, and blue to black, the whiter slag, as a rule, accompanying the production of grey iron, in furnaces working with light burdens, that is, a large proportion of fuel to ore and fluxes; while black slags indicate usually (though not invariably) a loss of iron, and a furnace working heavy burdens with the production of white iron. The same slag may be vitreous, stony, or vesicular in structure, according to the manner in which it has been cooled, quick cooling facilitating the production of the vitreous form, with a conchoidal fracture and more or less transparency at the edges, while slow cooling tends to make the slag stony, dull, opaque, and porphyritic in appearance. These characters, as well as the fusibility and fluidity of the slag, are also powerfully influenced by its composition; those slags in which earthy matters, as lime, magnesia, etc., occur in excess, are the least fusible, are of a dull stony character, and disintegrate spontaneously on exposure to air and moisture, while the presence of protoxides of iron and manganese, with large proportions of silica, form slags in which the fluidity and fusibility are more perfect, termed by the workmen *scouring* slags; a considerable proportion of alumina gives to the slag the opalescent character so frequent in the slags of Staffordshire furnaces smelting clay ironstones from the coal measures.

Blast-furnace slags are essentially double silicates of lime and alumina, in which the lime is more or less replaced by magnesia, iron, or manganese, and the silica sometimes partially replaced by alumina; they also contain about 1 lb. of potash per ton of slag, with probably some soda, as also sulphur, the presence of the latter element being promoted by the presence in the slag of manganous oxide and of lime. Analyses of a slag frequently found both in hot and cold blast furnaces of South Staffordshire has a composition corresponding to the formula, $2R_2O_3$, $3SiO_2 + 6$ ($2RO$, SiO_2), or if silica be regarded as SiO_3, this formula is equivalent to

R_2O_3, $SiO_3 + 2$ (3RO, SiO_3),* where R_2O_3 is a metallic sesquioxide, chiefly alumina, and RO a metallic protoxide, as lime, magnesia, or manganous oxide; in this slag the oxygen of the bases is *equal* to the oxygen in the silica, but the oxygen in the protoxides is *double* that of the sesquioxides. When slags containing sulphide of calcium, barium, or manganese are suddenly cooled by throwing water upon them, the sulphide is decomposed thus :—

$$CaS + OH_2 = CaO + SH_2$$
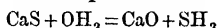
the presence of the sulphur under this treatment being readily recognised by the odour of the evolved sulphuretted hydrogen (SH_2).

The following table is collected from Percy's *Metallurgy of Iron* :—

ANALYSES OF BLAST-FURNACE SLAGS.

	Average of the analyses made by Mr Riley at Dowlais, from 13 furnaces working with hot blast.	Slag from a cold-blast furnace working with coke. (*Percy*).	Swedish charcoal furnace producing Bessemer pig-iron. (*Ullgren*).	A scouring slag like black bottle glass.
Silica, . . .	41·85	39·52	46·371	41·11
Alumina, . .	14·73	15·11	4·301	13·45
Ferrous oxide, .	2·63	2·02	0·950	6·44
Manganous oxide,	1·24	2·89	1·860	0·66
Lime, . . .	30·99	·32·52	38·640	29·82
Magnesia, . .	4·76	3·49	7·400	4·75
Potash, . .	1·90	1·06	0·300	1·84
Calcium, . .	1·15	} 2·15	·	} 1·34
Sulphur, . .	0·92		0·030	
Phosphoric acid,	0·15	...	Traces	0·15
Soda, . . .	...	...	0·138	...
	100·32	98·76	99·990	99·56

The presence of various metallic oxides in the slags impart to them characteristic colours; thus oxide of manganese produces a violet or amethyst colour when the slag is seen in mass, but not observed when the slag is in the vesicular condition; sulphide of manganese gives a yellow or brownish green colour, and oxide of iron renders the slag green or

* Percy, Vol. II.

black in colour; while alumina, oxide of zinc, or sulphide of sodium are said to impart a blue colour to the slags.

105. Reduction of Phosphorus.—It is observed that in smelting ores containing phosphoric acid under conditions favourable to the perfect reduction of the iron, that is, when little oxide of iron is allowed to remain in the slag, that at the same time phosphorus is absent from the slag, while the pig-iron produced will be contaminated with phosphorus; but that if the conditions be reversed, and a large quantity of the iron be left unreduced in the slag, it will at the same time be accompanied by the phosphoric acid if any be present, while the pig-iron produced will be comparatively free from phosphorus, from which it appears that the conditions most favourable for the perfect reduction of the iron are exactly such as are required for the reduction of the phosphoric acid, with the introduction of the phosphorus into the pig-iron produced. For this reason *cinder pig*, that is the iron produced from smelting mixtures containing a considerable amount of cinder or slag in addition to the ore, flux, and fuel, is always impure from the presence of phosphorus derived from the cinder so added. The pig-iron produced from pure ores or *mine* without any admixture of cinder, is called *mine pig* to distinguish it from the above.

106. Scaffolding, Bears, etc.—Scaffolds or collections of the smelting materials, arising from various causes, occur occasionally in the interior of blast furnaces, interfering with their proper working by obstructing the blast and free escape of the gases, with a consequent cooling of the furnace and thickening of the slags; they also prevent the proper descent of the charge to the twyers; and with the melting and withdrawal of the charge below the scaffold, together with the increasing weight of the charge above, the obstruction very frequently gives way, with the sudden descent, technically called a *slip*, of the charge to the hearth. These obstructions may arise from the faulty shape of the interior of the furnace, from the formation of a too difficultly fusible slag, the presence of too refractory ores, bad fuel—as a weak and friable coke which falls to powder under the weight of the superincumbent materials—or to imperfect charging apparatus, by which the larger pieces of the coke are

collected around the sides of the furnace, while the ore is distributed towards the centre. From whatever source arising, these obstructions are exceedingly troublesome, and attended with great difficulty in blast-furnace working.

From the sides and bottom of the hearths of blast furnaces that have been in blast some time, and then blown out, are frequently extracted large ferriferous masses known as *bears*, the composition of which is very various. They often contain iron, silicon, manganese, graphite, copper, red crystals of cyano-nitride of titanium, nickel, cobalt, and occasionally other rare metals.

107. Blowing-in a Furnace.—When commencing to work a new furnace, it is necessary that the masonry be thoroughly dried, and that this be not effected with too much rapidity, otherwise a fear of cracking the masonry arises. When it has been thoroughly dried, the operation known as *blowing-in* the furnace is commenced, for which purpose a quantity of wood is first introduced, and covered over with a considerable depth of coke, on which are superposed layers of coke and limestone, succeeded by a very light burden of ore; the furnace being now about one-third filled, the wood is ignited, and when fairly in combustion the furnace is filled to the top with a light burden of ore, fuel, and flux, and the blowing commenced, at first very gently, the amount of blast and burden of ore being gradually increased for a few days, when the normal burden and rate of driving may be attained.

CHAPTER VII.

MALLEABLE IRON.

Iron in its minimum state of carburation is designated as *malleable*, *bar*, or *wrought* iron; it then possesses a colour varying with its quality, and the mechanical treatment it has undergone, from bluish to blackish shades of grey. After melting it is decidedly crystalline or granular on fracture; but on rolling or hammering it assumes a fibrous structure, at the same time greatly increasing in tenacity. Its specific gravity ranges between 7·3 and 7·9, average specimens giving about 7·6 to 7·7; its linear and cubical expansion by heat are less than those of most metals, a bar expanding 0·000111 to 0 000126 of its length for each degree centigrade; its specific heat is 0·114, taking water as unity. The melting point of malleable iron varies with its degree of carburization: the larger the amount of carbon it contains, the lower being its melting point. Scheerer gives the melting point as 2000°C., but before fusion it passes through a soft pasty condition, in which, if two clean surfaces be brought into contact, and pressure applied, union takes place between the two, or, technically, the pieces are *welded* together, malleable iron possessing this quality of *welding* in the highest degree; at a red heat it may be hammered, forged, or rolled into any required form. The *malleability* and *ductility* of malleable iron are very considerable, increasing with the temperature to which it is heated, but these qualities are powerfully influenced by the presence of only small quantities of certain impurities; the presence of only 0·03 per cent. of *sulphur* rendering it *red-short*, that is, brittle and unforgeable while in the hot state; small quantities of *copper* also are attended with the same result; while *phosphorus*, on the other hand, renders the metal weak and brittle at ordinary temperatures,

or, as it is called, *cold-short*. Eggertz states the presence of 0·25 per cent. of phosphorus makes malleable iron sensibly cold short; 0·35 per cent. of *silicon* in bar iron induces *cold shortness*, at the same time lessening its tenacity. *Tin* hardens malleable iron, but at the same time renders it extremely brittle, incapable of being welded, and cold-short. *Antimony* and *arsenic* also produce a *cold-short* iron. *Titanium* present in pig-iron passes but in small quantities, if at all, into the malleable iron produced therefrom, and cannot accordingly influence its quality. *Zinc* and iron alloy well together,· as in the operation of *galvanizing* iron, in which an alloy of zinc and iron, formed by the immersion of clean iron plates in melted zinc, is deposited on the surface of the plate, such plates not being so readily oxidized on exposure to moist air. Continued hammering of iron in the cold state induces hardness and brittleness, with a more or less crystalline structure in the iron. Malleable iron undergoes no change in dry air, or water free from air ; but is rapidly coated with a scale of oxide or *rust* if exposed to the action of moist air, the oxidation and corrosion extending quite through the mass, if a sufficient length of time be allowed. Heated to redness, it rapidly oxidises, ordinary *forge scale* being an oxide so formed; while if heated to whiteness in the air, it burns with the production of magnetic oxide; bar-iron so heated, in contact with air, is technically called *burnt iron*, and is rendered thereby very friable, and incapable of being welded. The latter peculiarity is ascribed by some to an absence of carbon in burnt iron, and by others to the presence of oxide of iron in the mass due to the absence of carbon. Malleable iron is strongly attracted by the magnet, but cannot be permanently magnetised; heated to redness, and plunged into cold water, it retains its original softness; it is completely dissolved in moderately dilute acids, but very dilute hydrochloric acid leaves a carbonaceous residue. Malleable iron usually contains from 0·02 per cent. to 0·25 or 0·3 per cent. of carbon, but iron containing the latter amount of carbon is essentially steely in its character, 0·2 or 0·25 per cent. being the more usual limit to the carburization of malleable iron, which is, however, influenced by its freedom from other ingredients, especially silicon, sulphur, and phos-

phorus; the more free iron is from these elements, the larger is the proportion of carbon that can be combined with it without producing the steely quality. The tensile strength of malleable iron ranges from 17 to 26 tons per square inch, the average strength of the best qualities being from 23 to 24 tons per square inch, and a piece 2 inches long and $\frac{1}{2}$ inch in sectional area of such metal will stretch 40 per cent. of its length before breaking. The tensile strength is very much increased by wire drawing.

ANALYSES OF MALLEABLE OR BAR IRON.

Source,	Swedish.	Shortridge and Howel.	Low Moor.	Danne-mora.
Brand,	O O.	Armour Plate.	Armour Plate.	
Analyst,	Author.	Percy.	Tookey.	Schafhautl.
Iron.................	99·853	..	99·372	98·78
Carbon............	0·075	0·230	0·016	0·84
Sulphur............	0·032	0·190*	0·104*	...
Silicon	0·114	0·014	0·122	0·12
Phosphorus.......	0·004	0·020	0·106	...
Manganese........	Trace.	0·110	0·280	0·05
Nickel..............	..	..	Trace.	...
Cobalt.............	...	...	Trace.	...
Copper.............	...	..	. .	0·07
Arsenic	...	..	...	0·02

Bar-iron of commerce is designated as *No. 1 iron* or *puddled bar*, *No. 2* or *merchant iron*, and *No. 3* or *best iron*, while further treatment of the bar yields *best best* and *treble best* iron. These grades or qualities have reference chiefly to the treatment in hammering, piling, welding, and rolling of the metal after its conversion from pig-iron to malleable iron. For No. 1 iron, the bloom of malleable iron is removed from the furnace in which it has been produced, and hammered, or squeezed, and then passed at the same heat through the series of grooves in a train of rolls, whereby it is converted into a long flat bar, usually having a rough surface, and of dimensions varying with the purpose to

* Probably too high.

which it is to be applied. For the production of No. 2 or *merchant bar*, No. 1 is cut into lengths and piled into oblong rectangular masses, which are then raised to a welding heat in a reheating furnace, when the mass is hammered and re-rolled, or may be rolled without the intermediate hammering, the pressure of the rolls welding the various elements of the pile into one mass. This class of iron is the lowest that is available for smith's work. The process of cutting up, piling, reheating, and welding by rolling is repeated upon No. 2 for the production of No. 3, and so on. The size of the pile, manner of piling, and quality of irons introduced into any pile, depend upon the form and use for which it is intended. No. 3, or *best* iron, is tougher and more ductile than No. 2, and altogether better adapted to the uses of the smith; this is the quality designated in engineers' specifications as *best Staffordshire*. *Best best* is used for chains, rivets, etc.

Malleable iron is produced either *direct* from the ores, as by Siemens' process, and the Catalan process, the latter now only practised in the Pyrenees, India, Sardinia, and some parts of America and Africa; or by the *indirect process*, in which pig-iron is treated in furnaces so as to deprive it of almost the whole of its carbon, silicon, sulphur, phosphorus, and of certain rarer metals when these chance to be present in the original pig-iron.

PRODUCTION OF MALLEABLE IRON DIRECT FROM THE ORE.

108. Siemens' Process.—This process, as also the furnace employed for the production of malleable iron direct from the ore, is described under steel, p. 154.

109. Catalan Process.—This almost extinct process is conducted in a furnace, consisting of a hearth or four-sided cavity (fig. 21), somewhat wider at the top than at the bottom; the bottom is made of some refractory stone, as sandstone, granite, porphyry, etc., and is either flat or slightly concave. The back wall through which the twyer is introduced is formed by the brickwork of the building, faced by rectangular pieces of iron *a, a* to the level of the twyer, above which is stonework; the opposite side is convex outwards, and formed by pieces of iron *b, b* resting against the

masonry; of the two other sides, the one is formed of rough masonry, while the other, forming the front of the furnace,
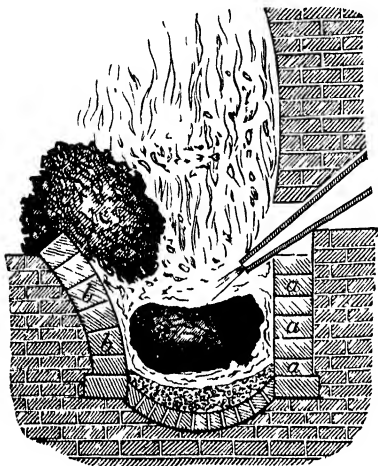
Fig. 21.—CATALAN FURNACE.

consists of two plates of iron, in the lower of which is made a hole for tapping out the slag from the hearth; the top edge of this plate serves also as a fulcrum for the bars employed in lifting the bloom of metal from the hearth. The twyer of sheet copper is introduced, as shown, through the side wall, the blast of cold air being maintained by a machine called a *trompe*, an apparatus consisting of two tanks, the upper one *a*, fig. 22,

communicating with a copious supply of water, and connected with the lower tank or air chamber *b*, by two wooden pipes or trees *c, c*, provided with holes at *d, d*, inclined as shown; the upper ends of the pipes are opened and closed by the introduction or withdrawal of the stopper *e* from the funnel-shaped mouth formed in the top of *c, c*; in *b* is an opening *f* for the escape of water, while the twyer is connected by sheepskin with the pipe *s*, joined to the flattened copper tube forming the twyer. By raising *e*, the water passes down *c*, drawing the air through the oblique openings *d, d* along with it, the water escaping from the chamber *b* by the opening *f*, while a continuous blast of air is thus maintained through *s*; this form of blast is, however, under the disadvantage of being always highly charged with water.

The twyer is usually inclined at from 30 to 40 degrees, but this varies with the degree of carburization it is desired

to attain in the product, the less the inclination the more slowly is the metal reduced, allowing a more lengthened contact of the reduced metal with the fuel, attended with a higher degree of carburization in the product, or the production of a steely iron, on the contrary, a greater inclination, promoting the rapid reduction of the iron is attended with the production of a softer metal.

In conducting the process, the hearth bottom, supposed to be heated from a previous charge, is covered with a coating of charcoal, and then the ore, usually an easily reducible brown hæmatite broken into small pieces, is placed against the side b, b, until the cavity is about one-third filled (if carbonates of iron be
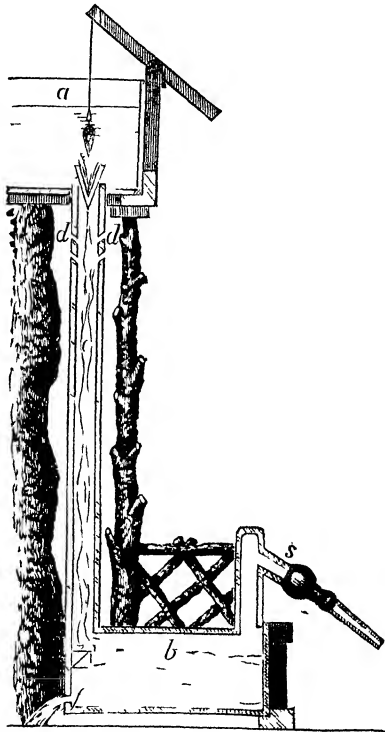
Fig. 22 —Trompe or Blowing Machine of the Catalan Furnace.

smelted, they must be first roasted or calcined), the space between this and the wall a, a is filled with charcoal; the whole is then covered with a layer of moistened charcoal dust and small ore. For the first two hours the full force of the blast is not employed, after which it is turned on full, and the workman pushes the descending pasty charge

towards the twyer, to allow of its fusion with the separation of the reduced metal from the slag; fresh quantities of small ore being continually added until the whole charge has been introduced. The metal and slag then collect in the hearth, from which the slag is tapped out at intervals by the hole in the front plate; in about 5 hours the reduction is complete, and, the blast being turned off, the spongy ball or mass of malleable iron, weighing about 3 cwt., is collected together, lifted out by the workmen, and shingled into a bloom, which is subsequently cut up and drawn out into bars.

In this process, the first effect of the heat is the expulsion of water from the ore, which, thus rendered porous and readily permeable by the ascending current of carbonic oxide (CO), is almost wholly reduced by this gas; the spongy mass so produced being then melted before the twyer, with the separation of the slag from the metal, a considerable waste of iron is at the same time necessitated; since, owing to the comparatively low temperature employed, it is necessary to maintain a very fluid slag or cinder, consisting essentially of a ferrous silicate of the formula $2\,FeO, SiO_2$, or in the old notation $3\,FeO, SiO_3$; such a silicate, in addition to its fluidity, also exercises a decarburizing effect upon the molten iron, whereby its combined carbon is oxidized to carbonic oxide, with the reduction of metallic iron from the slag. In this manner, from the low temperature at which the iron is reduced, together with the maintenance of a very fusible and fluid slag of silicate of iron, the carburization of the metal to the state of pig-iron is prevented, and the product is removed from the hearth in the state of malleable or at most a steely iron.

In India, malleable iron is made direct from the ore in furnaces, with shallow hearths and an artificial blast, resembling the ordinary smith's hearth; or in furnaces with shafts working either with or without an artificial blast. The charges are however small, the masses or blooms produced varying from 20 to 200 lbs. in weight.

110. Chenot Process.—This process is described, page 153.

111. American Bloomery Process.—Formerly the whole of the iron obtained in England was made by this process, by which malleable iron is made *direct* from the ore at one

operation, and which is still worked somewhat extensively in the United States and Canada. The following description of the furnace is from the report of Dr. Sterry Hunt:—The *bloomery hearths* or *low furnaces* measure from 27 to 28 inches, by 30 to 32 inches along the sides, and are only 20 to 25 inches in height above the twyer, and from 8 to 14 inches in depth below it. The sides, formed of cast-iron plates, about $1\frac{1}{2}$ inch thick, slope inwards and downwards, and rest in the more modern of the furnaces upon the hollow casting of iron which forms the bottom of the furnace, the latter kept cool by water circulating through it; in the older furnaces, instead of hollow iron castings, the hearth is formed simply by beating in clay or slag. The twyer is placed 12 inches above the bottom, and is inclined so as to make the blast strike the middle of the hearth, the twyer opening being a segment of a circle $1\frac{1}{2}$ inches in height, and $\frac{3}{4}$ inch wide. A water box is let into the twyer plate, through which a stream of water circulates for keeping the twyer cool, the water passing from it to the bottom plate of the furnace, where it serves a similar purpose. In front of the furnace, at 16 inches above the bottom, is a flat iron hearth 18 inches wide, in the side plate beneath which is formed a *tap hole*, through which the slag is withdrawn from time to time.

The blast heated to from 500° to 600° F. (280° C. to 320° C.), by passing through cast-iron syphon pipes placed in chambers above the hearth, is employed at a pressure of from $1\frac{1}{2}$ to 2 lbs. per square inch, except when smelting the finer magnetic sands, when the pressure is reduced to from $\frac{7}{8}$ to $1\frac{1}{4}$ lbs. per square inch.

The fire being lighted, and the furnace heaped up with charcoal, the powdered ore is scattered at short intervals over the top of the burning fuel; and in passing downwards to the twyer the metal is reduced, but without fusion, the grains of metal agglomerating in the hearth to the formation of an irregular mass or *loup*, while the earthy matters are separated as a liquid slag, which is tapped out at intervals. In about three hours, fuel and ore having been continuously supplied as the charge worked down, a mass or loup of about 300 lbs. in weight has collected, and is lifted by a bar from the hearth, and held for a few minutes before the twyer, so

as to obtain a welding heat, when the loup is shingled into a bloom, and is reheated in the bloomery fire for drawing it into bars; the fires thus working continuously, each produces about 2400 lbs. of blooms per day of twenty-four hours.

The ores employed in this process are rich and pure magnetic iron ores, and titaniferous iron sands; the latter, owing to their more refractory character, do not give such favourable results as the purer and more easily reduced magnetite, and the process is not applicable to the working of ores containing less than about 50 per cent. of metallic iron.

PRODUCTION OF MALLEABLE FROM CAST IRON, OR INDIRECT PROCESSES FOR THE PRODUCTION OF MALLEABLE IRON.

By far the largest proportion of the malleable iron now manufactured is obtained by subjecting pig or cast-iron to the operation of *puddling*, this process having almost entirely superseded the methods of production in the *finery* or *open-hearth* previously in use. This latter process is not to be confounded with the process of *refining* about to be described; for whereas the operations of the *finery* have for their object the production of malleable or wrought-iron, the product of the *refinery* is only a partially decarburized and imperfectly purified white iron, obtained by the treatment of grey pig-iron on the hearth of the refinery, and which is then cast in a particular manner, adapting it to the requirements of the puddling operation, or it is run directly from the refinery to the puddling furnace. As will be presently indicated, grey iron, owing to its perfect fluidity when melted, and also to the large amount of graphite which it contains, cannot be economically treated alone in the puddling furnace; but by subjecting it to the refining operation it is converted into white iron; thus, it will be observed that the treatment in the *refinery* is only *preliminary* to the puddling process in which malleable iron is produced, while the *finery* process produces malleable iron *direct* from the pig-iron.

112. Refining.—This process is employed in Wales, York-shire, and to a limited extent in other iron-making districts, preparatory to the conversion of pig-iron into the *finest* qualities of malleable iron by the puddling process; while,

for the manufacture of inferior classes, the pig-iron is not subjected to this treatment, but passes at once to the puddling furnace.

The refining process has for its object the removal of a considerable proportion of the silicon and slag-forming elements from the cast iron, with a reduction in the amount of phosphorus and sulphur present, as also the partial decarburization of the metal, with the conversion of its residuary carbon wholly into the combined form, this latter being effected by running the metal for the *refinery* into a long flat chill mould, and quenching quickly with water. By refining, the fluidity of the melted metal is rendered much less perfect, and it is thereby more readily acted upon in the puddling process. Pig-iron smelted by hot blast, containing usually a larger proportion of silicon and other foreign ingredients, accordingly suffers a greater loss in weight by the refining process than occurs with cold blast pig-iron, this loss amounting on an average to from 10 to 11 per cent. of the pig-iron operated upon.
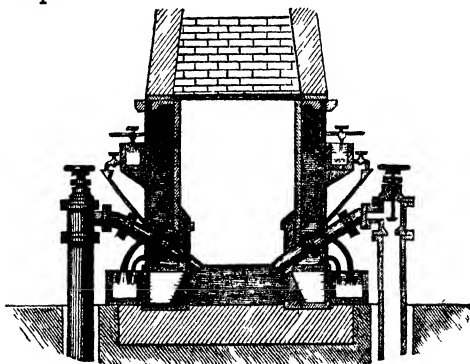
Fig. 23.—ELEVATION OF REFINERY.

The furnace employed in this operation, and known as the *refinery* or *running-out fire*, consists, as used in Wales, of a rectangular hearth *a*, figs. 23 and 24, about 4 feet square, and from 12 to 18 inches in depth. The hearth is bounded on two sides, and the back by hollow cast-iron *water blocks b, b,*

19—L.   H

through which a current of cold water is kept continually flowing; the front is formed by a dam-plate of cast-iron, containing the *tap hole*; *f, f,* are cast-iron plates closing the two sides, and secured to the pillars, which carry the stack or chimney *s,* from 16 to 18 feet in height; there are six twyers, *g, g, g,* three on each side of the hearth, inclined downwards at an angle of from 25° to 30°, the twyers in the two sides being arranged so that each directs the blast towards the space between the twyer openings on the opposite side, so distributing the blast more uniformly over the surface of the hearth; *h, h,* are water troughs for receiving the water from the twyers, which serve also to cool the tools employed in working the furnace. The back of the furnace is closed by wrought-iron doors, and the front by a wrought-iron door connected with a lever, by which it can be readily raised or lowered. The tap hole *l,* at the base of the dam-plate, allows the metal and slag to run out into the cast-iron mould *m,* beneath which water is maintained in constant circulation, so as to aid in the quick cooling of the metal, which is further promoted by throwing water on its surface; the cinder or slag remaining fluid longer than the metal, it is tapped from the surface of the refined metal into other moulds placed at the lower end of the mould receiving the metal.
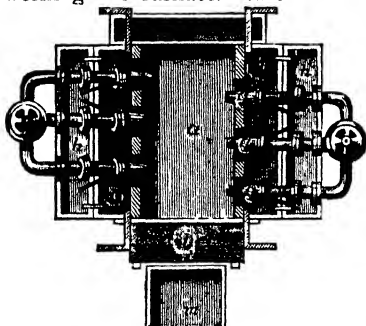
Fig. 24.—PLAN OF REFINERY.

The furnace employed in Yorkshire differs from the last or Welsh refinery, in having but five twyers, placed three on one side and two on the opposite, arranged as before, so as not to be directly opposed to each other.

The furnace being in operation, a quantity of coke is introduced through the folding doors at the back of the furnace, on which is placed alternate layers of pig or cast-iron and coke, until the charge of from one to two tons of

pig-iron and scrap has been introduced; a small quantity of hammer scale or slag is also sometimes added, such addition facilitating the process, and diminishing the loss of iron; a small quantity of lime is also frequently made with the view to the further elimination of sulphur, but this is effected more perfectly by the manganese of the pig-iron, owing to the more fluid slag which it produces. The top of the charge is then covered with coke, and the fire urged by the blast, when in from one and a half to two hours the whole of the metal has melted and run down into the hearth; fresh fuel is added, and the blast under a pressure of from 2 to 3 lbs. continued for a further period of half an hour, during which time bubbles of carbonic oxide escape from the melted metal, keeping its surface in agitation, whilst silicon and carbon, with smaller quantities of sulphur and phosphorus of the pig-iron, are oxidized; the silicon largely and most rapidly, with the production of a slag or cinder, consisting essentially of a tribasic silicate of iron (containing from 40 to 60 per cent. of iron), which floats on the surface of the metal. Fresh coke is added from time to time, and the heat maintained until the action has proceeded sufficiently far, the time varying much according as white or grey iron is under operation, grey pig-iron requiring the longer time for its treatment. When the refining is completed, the metal and slag are tapped out together, cooled, and separated in the manner described. About 3 cwt. of coke is consumed per ton of metal, and the weekly produce of the refinery varies from 80 to 150 tons, according as the charge consists of grey or white iron.

The *refined iron, fine metal, plate metal,* or simply *metal,* as the product obtained by this process is called, is almost silver white in colour, has a bright fracture, the upper portion of the plate being more or less cellular. The plates of metal are from 1 to 3 inches in thickness, a foot wide, and 12 or 14 feet in length, often furrowed on their under surface, and rendered brittle from their sudden cooling, thereby facilitating the breaking of them into pieces suitable for introduction into the puddling furnace.

The following analyses show the very marked decrease in the silicon with the smaller diminution in the amount of the

carbon, phosphorus, sulphur, and manganese, effected by the refining process:—

ANALYSES OF REFINED IRON.

	FRANCE (*Regnault*).		EBBW VALE (*Noad*).		BROMFORD (*Dick*).
	Pig-Iron.	Refined Iron.	Pig-Iron.	Refined Iron.	Refined Iron.
Iron	92·3	97·8	...	...	95·14
Carbon........	3·0	1·7	Graphite 2·40	0·30	3·07
Silicon	4·5	0·5	2·54	0·32	0·63
Sulphur	...	...	0·22	0·18	0·16
Phosphorus...... ..	0·2	...	0·13	0·09	0·73
Manganese..........	...	...	0·86	0·24	Trace
Insoluble Matter..	...	...	...	...	0·14

The slag or cinder from the refinery, as already stated, is essentially a ferrous silicate containing from 40 to 60 per cent. of iron with the greater part of the manganese, and a portion of the sulphur and phosphorus from the pig-iron, with the ash of the fuel; it is a dark bluish, or black, vitreous or lustrous mass.

ANALYSES OF REFINERY CINDER OR SLAG.*

	DOWLAIS (*Riley*).		BROMFORD (*Forbes*).
	Ordinary Cinder.	Crystallized Cinder.	Crystallized Cinder.
Ferrous oxide (FeO)	65·52	54·94	61·28
Silica	25·77	33·33	22·76
Manganous oxide (MnO)	1·57	2·71	3·58
Alumina....................	3·60	5·75	7·30
Lime........................	0·45	1·19	3·41
Magnesia..................	1·28	0·50	0·76
Sulphur....................	0·23	...	0·46
Sulphide of iron..........	...	0·27	...
Phosphorus...............	1·37	0·99	...
Copper.....................	...	Traces.	...
Percentage of iron	50·96	42·84	47·66

In Silesia the refining has been effected by treating the iron on the bed of a reverberatory furnace with gaseous fuel, a movement of rotation being imparted to the melted metal on the hearth, by the blast impinging obliquely upon it at two opposite sides.

113. Puddling Process.—This process, introduced by Henry Cort in 1784, differs from the method of producing malleable iron in the *finery* or *open hearth* to be subsequently described, by treating *pig-iron* or the *refined metal* from the last operation on the bed of a reverberatory furnace, or other chamber separated from the grate on which the fuel is burnt, whereby the metal and fuel are not brought into contact as occurs in the finery, the temperature of the puddling furnace being maintained by the flame, and heat produced by the combustion of the gaseous products of the furnace; the process thus allowing of the utilization of raw coals and other inferior fuels, which could not be applied in the finery, where the fuel and iron are brought into contact with each other.

The methods of puddling are divisible into two classes, according as the decarburization is effected chiefly by the strong current of air (produced by the draught of a chimney or stack), assisted in a minor degree by the addition of oxidizing or readily reducible materials as hæmatite, forge-scale, magnetic oxide of iron, and basic slags of silicate of iron, in which case the operation is known as *dry puddling;* or if these latter substances afford the chief supply of oxidizing materials, the air performing this part only in a lesser degree, then the process is designated as *wet puddling* or *pig boiling.* The bottom of the furnace in the two cases being slightly altered in depth, form, and nature of its lining.

Grey pig-iron, as requiring a higher temperature for its fusion, coupled with its more perfect fluidity when melted, is not so suitable for conversion into malleable iron as is white iron, which melts at a lower temperature, and previous to fusion passes through a pasty condition highly favourable to the action of the atmosphere or other oxidizing substance upon the carbon, silicon, sulphur, phosphorus, manganese, and other elements of the pig-iron, which it is the object of the puddling operation to remove. The treatment of grey cast-iron in this process entails considerably more labour

upon the puddler, for unless the metal is continually stirred, or as it is called *rabbled*, so as to bring fresh portions in contact with the air and slag, the iron will sink down as a fluid mass beneath a layer of slag or cinder, which prevents the contact of air and thus delays the *fining* of the metal, with the necessarily increased expenditure attendant thereon; hence one of the necessities for converting grey into white iron in the refinery, before subjecting it to the puddling process.

The first stage in the operation of puddling consists in the removal, to a great extent, of the silicon; and the conversion of any grey into white iron, that is, any graphite that may be present must pass into the state of combined carbon before any appreciable decarburization of the metal occurs; this completed, the manganese, phosphorus, sulphur, and carbon, with a proportion of iron, are oxidized, either by the free oxygen of the atmosphere, or by the oxygen of the oxides of iron added to the charge, with the production of a fusible slag or cinder of silicate of iron and manganese with earthy matters, phosphoric acid, etc., and the evolution of carbonic oxide, which burns with its characteristic flame in jets from the surface of the molten metal.

In the boiling or wet process, the decarburization is chiefly effected by the reduction of the oxides of iron contained in the cinder or slag; and this reduction of iron from the slag, with decarburization of the melted metal, takes place more readily the more basic or richer the slag in oxide of iron; thus in the earlier stages, or during the melting down of the iron, the silica is being oxidized, and the slag is highly siliceous, and but little reaction ensues between it and the carbon of the pig-iron; but as the process proceeds, and the iron becomes oxidized by the air, the basicity of the slag increases, when a reaction ensues, by which carbonic oxide is copiously evolved, escaping through the liquid slag with a corresponding decarburization of the pig-iron, and the reduction of iron from the slag or cinder.

The elimination of sulphur from the pig-iron during the puddling operation is always very imperfect, a portion only passing into the cinder, probably as sulphide of iron; while phosphorus, through prolonging the puddling operation, always occurs largely as phosphoric acid in the tap cinder,

about 80 per cent. of the phosphorus present in the pig-iron being removed by the puddling process, but the exact reactions by which the elimination is effected are not very well understood, Percy suggests that it is probably separated by a kind of liquation, first entering the cinder as a phosphide of iron, liquated from the malleable iron when in its pasty condition, and that the phosphorus is subsequently oxidized to phosphoric acid.

114. Puddling Furnace.—The puddling furnace is a reverberatory furnace in which the proportion of grate area to that of the bed is very large, the size of grate varying according to the kind of coal consumed, from one-half to one-third the area of the bed of the furnace. Figs. 25, 26, and 27* represent a South Staffordshire furnace which may be taken as a type of this class, though the exact form of bed, and method of supporting the cast-iron plates forming the bottom, differ in various districts. The bed a of the form shown in fig. 27, is separated from the rectangular fireplace b by a low hollow fire-bridge c, and from the flue d by a similar bridge e called the flue-bridge. These bridges are here shown hollow, to allow of the circulation of air through them; in other furnaces, instead of the separate iron plates here illustrated, hollow castings are substituted, which form a channel around the bed, in which a current of water circulates. The roof, formed of fire-brick, is a low flat arch, sloping slightly towards the flue end, the flue itself being built with a slope downwards to the base of the stack; the brickwork of the furnace is supported by cast-iron side plates bolted together, and tied to those of the opposite side by tie-rods passing over the top of the furnace. The bars of the grate are ordinary bars of wrought-iron, supported on bearers at their extremities; there is no furnace door, the fuel being charged through an opening f in the front or working side of the furnace, situate about 10 inches above the fire-bars, over which the fuel is spread by the workman using a hooked bar of iron; and when the firing is completed, the aperture is closed by inserting lumps of coal in the opening, on to which a small quantity of small coal is thrown. The flue and fire-bridges are formed of fire-brick, encasing the frame of the cast-iron

* Percy, Vol. II.
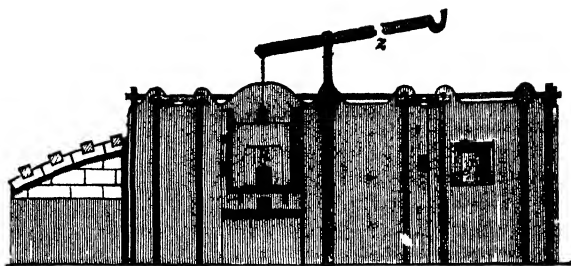
Fig 25 —Elevation of Puddling Furnace
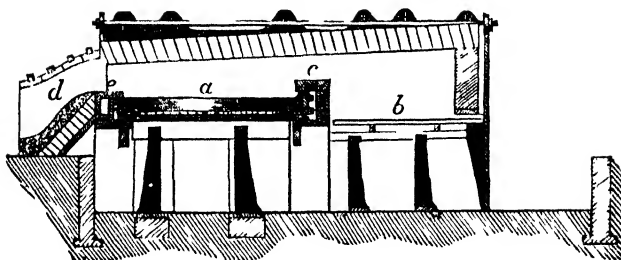
Fig 26 —Vertical Section of Puddling Furnace.
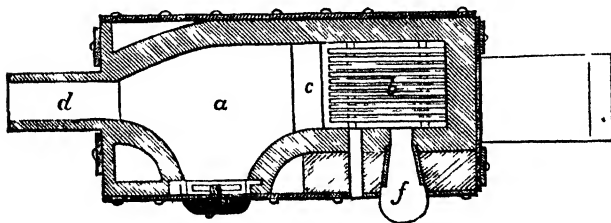
Fig. 27.—Plan of Bed of Puddling Furnace.

bottom, beyond which the upper course of brickwork, formed by quarries or slabs of fire-brick, is made to project inwards as shown, to allow of the introduction of the *fettling* or lining of refractory material for protecting the side plates. The bottom of the furnace is formed of cast-iron plates rabatted together, and supported upon pillars or bearers resting on side plates or brackets also of cast-iron. The working door *g*, placed at one side of the furnace, consists of an opening about 10 inches above the furnace bottom, and closed by a door formed of fire-brick slabs or quarries fixed in an iron frame, and suspended by a chain from the lever *z*, by which it can be raised for introducing the charge or withdrawing the puddled ball; a notch *h*, formed in the lower edge, and called the *stopper hole*, is for the introduction of the iron bar or *paddle* used by the puddler in *rabbling* or stirring the metal, the side of the notch acting as a fulcrum for the bar; below the working door is the *tap hole i*, stopped with sand during the working of the furnace, and through which the slag, or, as it is called, *tap cinder*, which remains on the hearth, is withdrawn at intervals as required. The stack of the furnace, the height of which varies considerably according as it is connected with one or more furnaces, if for one furnace only, is usually from 30 to 50 feet in height, and is surmounted by a flat plate or damper connected to one end of a simple lever, from the opposite end of which is suspended a chain, sufficiently long to be within reach of the puddler, the proper regulation of the draught forming an important part in the puddling operation. The working bottom of the furnace used in *pig boiling* or *wet puddling*, is formed by covering the iron plates already mentioned with a coating of refractory material rich in oxide of iron, such as tap cinder, hammer scale, etc., mixed with broken up bottoms of old furnaces; for this purpose a layer of broken slags, hearth bottoms, etc., are first introduced, and the heat raised so as to fuse or soften it, when it is spread evenly over the bottom, forming a layer of about 3 inches in depth; the side plates are covered, or as it is called *fettled*, with a lining of broken up, roasted *tap cinder*, called *bull dog*, which is rammed in under the projection of the fire-brick quarries on the top of

the fire-bridge, and then the surface is levelled up with a paste of soft red hæmatite called *puddlers' mine*, the fettling so prepared extending more or less over the furnace bottom.

If a new furnace bottom has been put in, the first heat should consist of scrap iron, with a small quantity of refined metal; when, by the high temperature and oxidizing atmosphere maintained in the furnace, the bottom becomes thoroughly consolidated and coated with a layer of slag consisting largely of oxide of iron, which is but little acted upon by the silicon of the pig-iron introduced in future operations. Fettling of the side plates is required after each heat, and after each shift of twelve hours sufficient scrap iron to form a ball is introduced into the furnace, and worked into a bloom, for the purpose of coating the bottom of the furnace with oxide of iron. A puddling furnace in continual use will require rebuilding in about six months.

Of the numerous proposed improvements in the class of puddling furnace already described, may be noted that of Detmore, tried at Ebbw Vale, and consisting of an arrangement for introducing a blast under the grate, using a *closed* ash-pit, with washed small coal as fuel; another introduces the blast below the grate, with an *open* ash-pit, when small coal, half caking, and half free-burning was proposed to be used.

Double puddling furnaces have of late been received with favour, as admitting of heavier charges with a larger production and economy in fuel; but the wrought-iron produced is not likely to be so uniform in quality, due to the increased amount of air and the longer time employed by puddling in the double furnaces, as also from unequal skill in the puddlers working the two sides of the furnace. In these furnaces the hearth and grate are both made larger than single furnaces, and the two working doors are placed one along each side of the furnace, through which the metal is worked by two men at the same time, viz., one at each door.

115. Manipulation of the Puddling Process.—The details of the working of the puddling furnace differ according as white, grey, or refined iron, or a mixture of these with hammer slag, etc., is under treatment. If the charge

consist of white or forge pig-iron alone, the heat is maintained higher at the commencement of the operation than when grey iron constitutes the charge.   The proper regulation of the damper, as controlling the temperature of the furnace and amount of air passing through it, is of considerable importance, and requires to be raised and lowered several times during the progress of a single heat.

In conducting the puddling process, the furnace heated from a previous operation, and containing some rich cinder from the previous charge, is charged with about 4½ cwt. of metal, introduced through the working door, the latter being then lowered, fixed, and luted in position; the damper is raised, and the fire made up, when, in about fifteen minutes, the puddler inserts his *paddle* or bar through the stopper hole and moves the pigs about, so as to heat them and the furnace bottom more uniformly, and in from thirty to thirty-five minutes the first or melting down period is completed ; the damper is now lowered, and the metal continually stirred, or, as it is called, *rabbled*, so as to thoroughly incorporate the metal, cinder and hammer scale or mill cinder with the charge, after which the damper is raised, and in about forty-five minutes from the commencement, the bath of metal swells and rises up rapidly ; jets of carbonic oxide, due chiefly to the oxidation of the carbon in the pig-iron, by the reaction between it and the oxidized compounds of iron existing in the basic slag called *cinder*, which is mixed with and covers the metal, burning with its characteristic blue flame from all parts of the surface of the bath, gives to it the appearance of ebullition or *boiling ;* during this stage, which lasts about a quarter of an hour, the puddler, moving his paddle or bar continually from the centre of the bath towards the bridges, rabbles vigorously the metal in all parts of the bath.   The metal then begins to thicken, the cinder gradually sinks, and the surface exhibits bright points or specs of malleable iron, or, technically, the iron *comes to nature*, the points, increasing in size, become pasty masses, which are broken up by the workmen, and the heat somewhat raised so as to effect the better separation of the cinder or slag from the metal, when the detached particles of metal are rolled over the surface of the bed, until the nucleus so

commenced with, collects upon itself sufficient metal to form a ball of from 70 to 80 lbs. in weight, which is then rolled towards the fire-bridge, where it remains until the whole charge has thus been collected or *balled up* into about six balls; a final heat is given so as to promote the ready expulsion of the cinder, and the welding together of the particles of iron under the hammer, squeezer, or other shingling machine to which the puddled ball is at once transferred. The balls are drawn separately to the working door of the furnace, and lifted by a pair of tongs with curved jaws from the furnace to an iron truck, or they are dragged along the floor to the shingling apparatus, the working door being closed and the damper down, so that the furnace is kept filled with a smoky flame, preventing the oxidation of the other balls during the treatment of the first.

The cinder, which only requires to be tapped out after each second heat, is tapped into a wrought-iron waggon placed under the tap-hole, immediately after the withdrawal of the last ball; but in dry puddling, where white or refined iron only is treated, the amount of silicon not being so great as in the last or boiling process, where mixtures of grey, mottled, and white iron are introduced, less slag is produced, and hence requires tapping out only after several heats have been worked off.

The whole operation, from introducing the charge to the withdrawal of the last ball, constitutes a *heat*, and lasts about an hour and a half, but may be longer or shorter according to the amount of impurity present in the pig-iron, the presence of sulphur and phosphorus in the pig-iron especially retarding the conversion into malleable iron. In Staffordshire, in a *turn* or *shift* of twelve hours, from five to seven heats are worked off; but in Scotland the pig, being a dark grey siliceous metal, smelted from blackband ores, only from four to five heats are worked off in the same time; and at Low Moor, Bowling, Farnley, and other districts of Yorkshire making best qualities of malleable iron, the pig employed is cold blast iron, usually refined before puddling, and puddled in charges of from 2 to 3 cwt., in slightly smaller furnaces, maintaining a somewhat higher temperature than the former, and the rabbling is more continuous

than is practised in Staffordshire. With this nine or ten heats can be worked off in the day of twelve hours.

Small quantities of Cumberland hæmatite, or of peroxide of iron, are added at some works to assist in the conversion by the boiling process. The addition of a mixture known as *Schafhäutl's* powder, consisting of common salt, peroxide of manganese, and clay, is also sometimes made with a view to the more perfect elimination of the sulphur and phosphorus in the pig boiling. Scrap iron added towards the end of the operation is considered to improve the quality of the product.

In puddling by the dry method (that is, in a furnace of which the iron bottom is coated with but from 1 inch to 1½ inches of a lining, consisting largely of oxide of iron, formed by working a ball of scrap iron on the bed while maintaining an oxidizing atmosphere in the furnace, and then spreading it while at a high temperature over the furnace bottom; or, as formerly, in a furnace the bottom of which was simply covered with sand, thinly glazed with slag), the charge is placed around the sides of the bottom of the furnace, the centre being kept empty. When the metal assumes a pasty state, the damper is lowered to prevent its becoming perfectly fluid; and while in this pasty condition, it is drawn down towards the middle of the hearth, broken up, and rabbled, so as to thoroughly mix the metal with the oxide of iron formed during the first or melting stage, and that added at intervals in the form of hammer scale. The rabbling is continued, and reaction ensues between the carbon, hammer scale, and oxygen of the air, but the decomposition is not so vigorous as in the boiling process; as before, when the metal "comes to nature" or to "*dry*," it becomes less fusible, and the damper is raised to allow of the metal being balled up. This process is attended with the formation of a smaller amount of slag or cinder, due to the smaller amount of silicon in the metal treated, is of shorter duration than the wet or boiling process, and accordingly consumes less fuel; but it can only be applied economically to white or refined iron, and unless comparatively pure ores have been employed, the malleable iron produced is inferior in quality. In dry puddling the heat does not rise so high as in "pig boiling,"

and there is an absence of the addition of cinder to the charge.

116. Loss in Puddling.—The loss of iron in the conversion into malleable iron by puddling, varies much according to the purity of the pig-iron; the less siliceous the pig, the larger will be the yield. In "pig boiling" the loss is greater than in the dry method, but not so great as the total loss entailed by refining with the subsequent puddling. In Staffordshire, the loss of weight between the pig-iron charged and the puddled balls produced is from 7 to 10 per cent.; while pig boiling in Scotch ironworks, treating, as already mentioned, a siliceous pig smelted from blackband, the loss is from 15 to 18 per cent. of the weight.

117. Tap Cinder.—The slag, or, as it is called, "*tap cinder,*" produced in the puddling operation is a highly basic silicate, containing from 45 to 55 per cent. of metallic iron, existing as ferrous and ferric oxides, and containing in addition usually manganous oxide, alumina, lime, magnesia, ferrous sulphide, phosphoric acid, and probably phosphide of iron; but the composition varies at different stages of the process. In the earlier or melting down stage it is more siliceous, from the oxidation of the silicon of the pig-iron by the oxygen of the atmosphere, and also from the

ANALYSES OF TAP CINDER.

	Cinder from Boiling of White Iron. (*Riley*).	Staffordshire Cinder. (*Percy*).
Silica	7·71	23·86
Ferrous oxide (FeO)	66·32	39·83
Ferric oxide (Fe_2O_3)...........	8·27	23·75
Manganous oxide (MnO)	1·29	6·17
Alumina..........................	1·63	0·91
Lime..............................	3·91	0·28
Magnesia.........................	0·34	0·24
Ferrous sulphide................	...	0 62
Sulphur	1·78	...
Phosphoric acid	8·07	6·42
Copper...........................	Traces.	...
Metallic iron	57·37 per cent.	47·60 per cent.

presence of sand attached to the surfaces of the pigs of iron; while at the end of the operation, when the metal comes to nature, the heat is partially maintained by the oxidation of the iron itself, with an increased basicity of the cinder.

118. Gas Furnaces.—The construction of puddling furnaces, using gaseous fuel, varies with the materials employed for the generation or production of the gas, and the mode of effecting its combustion.

The Carinthian gas furnace, consuming the gases from air-dried wood, lignite, or peat as fuel, consists of a rectangular chamber or *producer*, of considerable depth, built at one end and separated by a bridge from the hearth of the furnace; a second bed, used for heating the metal for the succeeding charge by the waste gases, is placed between the furnace hearth and the stack. The combustion in the producer is maintained by a stream of air introduced by a pipe into the bottom of the chamber, at a pressure equal to about half an inch of mercury, while the combustion of the gases is effected on the hearth or bed of the furnace by a blast of air, heated to about 200° C. or 392° F., by circulation through the hollow cast-iron bottom plates of the bed, introduced into the furnace by an oblong inclined twyer immediately above the fire-bridge, and extending the full width of the furnace.

119. Siemens' Regenerative Gas Furnace.—In these furnaces inferior qualities of fuel, as coal slack, coke, lignite, and peat can be utilised, thereby effecting a considerable saving in the cost of fuel; a higher and more uniform temperature can be maintained than is attainable in the ordinary furnaces, with a greater purity of flame, an oxidizing, neutral, or reducing flame being obtainable by varying the relative proportions of air and gas admitted.

The furnace consists of three parts, 1° the *producer* or chamber in which the gases are generated; 2° the *regenerators* or chambers for storing the waste heat of the flame and gases from the furnaces, to be subsequently used in heating the air and gases before combustion on the furnace bed; and 3° the furnace proper. As applied to puddling, the furnace is similar to that illustrated on p. 179, used in steel

melting; the bed is formed of cast-iron plates, and the sides by hollow boxes, kept cool by the circulation of water through them, the water passing into a tank beneath the bottom, the evaporation from which assists in keeping the bottom plates cool; at each end of the bed of the furnace, as illustrated in fig. 28 (representing a plan of the bed or bottom), are open-
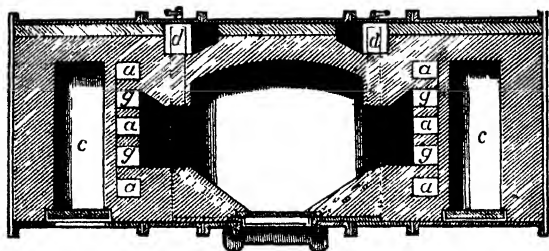
Fig. 28.—PLAN OF THE BED OF SIEMENS' PUDDLING FURNACE.

ings *a*, *a*, *a*, and *g*, *g*, through which air and gases are admitted respectively at one end, and withdrawn through corresponding openings at the opposite end into the regenerators, and so to the stack; and by suitable valves, the course of the current can be reversed so as to traverse the furnace in just the reverse direction. Placed at each end of the furnace are two chambers *c*, *c*, which may be used for heating the pig-iron to redness during the balling up of the previous charge, and prior to its introduction on to the bed of the furnace; *dd* are small ventilating shafts for carrying away the steam produced by the evaporation of the water beneath the bed.

The *producers*, fig. 29, are rectangular chambers of fire-brick, the front side *a* of which is inclined at an angle of from 45° to 60°, at the foot of which is the grate *b* of fire-bars, slightly inclined and supported in the ordinary manner; the fuel is supplied through *c*, the chamber *d* forming a kind of hopper, which is maintained well charged with fuel, so that the latter continually descends as required to the bars or furnace proper, without opening the furnace chamber to the atmosphere when charging the fuel; a small opening at *e*, closed by a plug, permits of an inspection of the interior, and the insertion of a bar to spread the fuel if required. If the

producers be not sufficiently below the furnace to maintain a pressure outwards in the pipes slightly above the atmospheric pressure, then the gases are conveyed by the stack or pipe *f*, from 8 to 10 feet in height, into the horizontal *cooling tube g*, from whence they are conducted downwards,
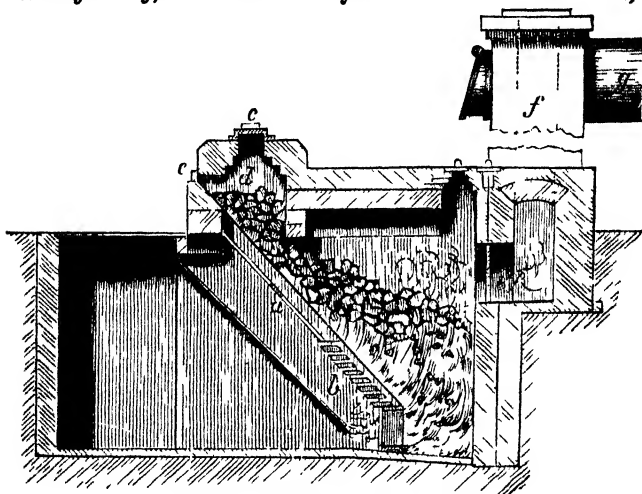
Fig. 29.—SIEMENS' GAS PRODUCER.

either directly to the furnace, or to a brick flue beneath the ground, from which several furnaces may be supplied, and into which the gases from several producers are conveyed; by means of the stack *f* and cooling tube *q*, a pressure is maintained within the pipes or flues, sufficient to prevent the combustion of the gases by air passing into them through crevices in the brickwork. The combustible gases arising from the producer are various hydrocarbons, the products of the distillation of the coal in the upper portion of the producer; carbonic oxide, formed by the reduction of the carbonic acid produced at the fire-bars by the combustion of the fuel, which, passing over the heated coke or carbonaceous matters formed in the upper layers, combines with an additional atom of carbon, with the production of two volumes of carbonic

oxide, thus, $CO_2 + C = 2\,CO.$; and hydrogen formed by the decomposition of the water introduced in small quantities into the ash-pit, the steam from which, passing over the incandescent fuel, yields carbonic oxide and hydrogen, thus, $OH_2 + C = CO + 2\,H.$

The *regenerators* are vaulted chambers of fire-brick placed beneath the furnace, in which are stacked masses of open brickwork as shown in fig. 45, p. 179, allowing the passage of air or gases through them; these are worked in pairs, admitting air and gas respectively to the furnace, of which the air regenerator is considerably larger than that admitting the gas, the maximum proportion being about 7 to 4. The gases having undergone combustion, the products are drawn down by the draught of the chimney, through the pair of regenerators at the opposite end, whereby, instead of the flame and products of combustion escaping to the chimney at a very high temperature, the heat is absorbed by the bricks, the gases passing out at the chimney, having a temperature of only about 149° C., or 300° F. The course of the escaping gases being from above downwards through the regenerators, the upper layers of brickwork are heated somewhat more than the lower courses.

In working the furnace, the gas and air controlled by independent valves, enter at the bottom of separate regenerators, thus passing from the colder to the hotter portion of these chambers. The gases and air thus heated mix with each other at the bridge of the furnace, where combustion or chemical combination ensues between the two, attended with the production of a most intense heat; and by admitting a greater or less proportion of air into the furnace, an oxidizing, neutral, or reducing flame can be maintained; as also by allowing a larger or smaller volume of gases to enter, the temperature of the furnace can be regulated. On first lighting the furnace, the air and gases meet in the furnace chamber or hearth in a cold state, and require to be lighted, when the combustion will continue, and the temperature be gradually raised, the regenerators at the opposite end becoming heated; after effecting which, the current is reversed, and the gases and air pass through the heated pair of regenerators, abstracting their heat, while

the opposite pair are being heated by the escaping flame and products of combustion.

By the use of this furnace in the puddling process, a saving of from 7 to 10 per cent. is effected in the amount of iron wasted, and the saving in fuel is very large, variously estimated at from 20 to 50 per cent.; it also works off a greater number of heats per shift; but in working upon pig-irons containing sulphur and phosphorus, these elements do not appear to be so perfectly removed as in the ordinary furnace, the product accordingly being inferior in quality.

120. Mechanical Puddling.—The work of the puddler is more laborious than any other involved in the manufacture of iron, and for lessening its amount and rendering it more simple, various contrivances have been proposed. Nasmyth proposed to introduce high pressure steam through a tubular rabble into the contents of the furnace; but its use has been discontinued. The mechanical rabble proposed by Mr. Eastwood, is a tool suspended from a lever overhead, and actuated by screw and worm gearing, whereby a compound motion is produced which has the effect of moving the rabble over every portion of the surface of the hearth. Ellerhausen proposes, as described under his steel process, to effect a mixture of the liquid pig-iron, as it runs from the blast furnace, with oxidizing materials, as hæmatite and magnetite, instead of making the mixture on the hearth of the puddling furnace as practised in ordinary puddling; but the more promising methods are those in which motion is communicated to the hearth of the furnace, and amongst the workers in this direction may be noted Tooth, Menelaus, Bessemer, and Danks, of whom the latter has introduced a furnace which promises to become a success. The great difficulty in furnaces of this description has hitherto been to obtain a lining capable of withstanding the action of the large rolling ball of metal, and of the slag, under the new conditions of a revolving bed; this Mr. Danks appears to have accomplished.

121. Danks' Furnace.—The working part, bed or refinery, of this furnace, consists of a horizontal revolving chamber A, built up of cast-iron plates, and lined with a very refractory material; it is supported and kept in position by four

rollers b, b, and rotated by the spur wheel c gearing with a pinion, driven by a small reversible engine attached to each furnace. The ends of the chamber are contracted in diameter,

30 — VERTICAL SECTION OF DANKS' REVOLVING PUDDLING FURNACE.
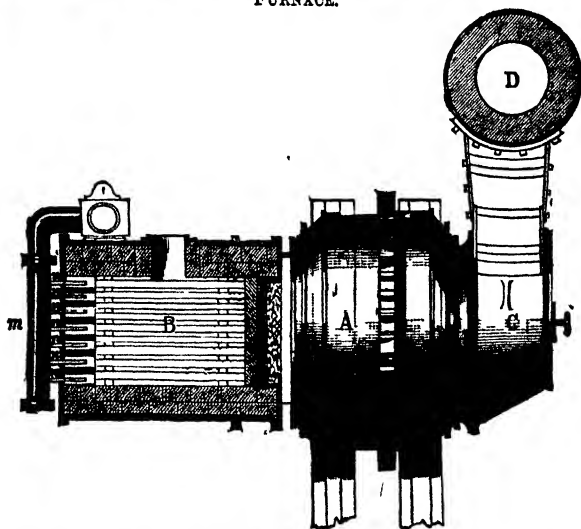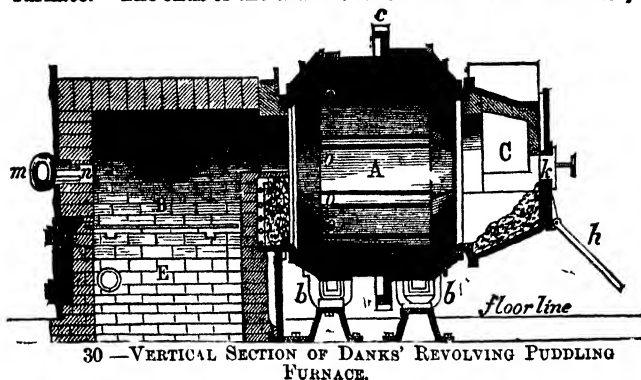
Fig. 31.—PLAN, HALF IN SECTION, OF THE DANKS' PUDDLING FURNACE.

one extremity communicating with the chamber or fireplace B, while the other end opens into the movable chamber or elbow flue C, leading to the fixed chimney D. Into the ash-pit E, closed by folding doors during the working of the furnace, is introduced a fan blast, and at the grate end of the furnace is a blast-main *m*, communicating by a number of small twyers, *n, n, n*, with the interior of the furnace, introducing a blast above the fuel, the combustion of which is thus rendered more perfect, the supply of air being regulated by a valve under the control of the workman, who can thus adjust the temperature of the furnace according to the requirements of each stage of the process. The fire-hole, unlike the ordinary puddling furnace, is closed by a door, kept cool by a coil of pipes surrounding it, through which cold water circulates; in a similar manner the bridge between the fire and the rotating chamber, and also the end plates of the revolving chamber most exposed to the heat, are kept cool. The movable chamber or elbow C, through which the gases pass from the chamber A to the chimney D, is suspended by rods from a carriage sliding on an overhead jib or rail, and is kept in its place, except when charging or removing a ball, by the supports *h*; in the end of C is a *stopper hole k*, through which the progress of the operation within the puddling chamber can be observed. The revolving chamber, formed of cast or wrought iron segments connecting its two ends, is fitted with hollow ribs *o, o, o, o*, running lengthwise, which serve to keep the plates cool, and also to hold the *fix* or *fettling*.

The inside of the revolving chamber is first lined with an *initial* lining of a pulverized iron ore and lime, made into a thick paste with water, upon which, when dried, is thrown a quantity of pulverized iron ore or hammer slag, the chamber is then heated and revolved slowly, until the initial lining is completely glazed; upon the initial lining so prepared is introduced an inner lining, and for this purpose iron ore, as pottery mine and scrap, are then introduced and melted, forming the *fixing*, and into the melted bath or fixing so formed, lumps of iron ore, as ilmenite (a titaniferous iron ore), are thrown, the lumps of ilmenite projecting above the surface of the bath; this is allowed to set, when another

layer of fixing and ilmenite is introduced in the same manner, the operation being repeated until the chamber is completely fettled. The ores used in fettling this furnace · are the ordinary fettling materials used for puddling furnaces, such as Bilbao ore, "blue billy" (the residue from the burning of iron pyrites at sulphuric acid works), and hæmatites; but the slags, bull-dog, etc., ordinarily used are unavailable.

The charge of pig-iron is inserted at the chimney end, and as it melts, the revolving chamber A is set in motion; the iron is then carried partially around and rolls down the sides to the bottom of the vessel, and as it melts is carried farther around, running and dropping continually from the sides and top towards the lower part of the chamber, thus exposing the metal thoroughly to the action of the heated air and gases. In these furnaces the charge, from 600 to 700 lbs., is larger than the charge of the ordinary furnaces, and is collected by the furnace into one ball, which is withdrawn through the end, by removing the elbow flue C, and inserting a large forked lever carried by a crane, when, by a small rotation of the chamber, the ball is turned on to the forked end of the lever, which is then withdrawn, and the ball conveyed to be shingled.

The puddled balls obtained range about 10 per cent. heavier than the charge of pig-iron introduced, probably due to the reduction of an amount of iron from the ore used as fettling.

122. Utilization of Waste Heat of the Puddling Furnace.—The flame and gases escaping from puddling and reheating furnaces, except those arranged on the Siemens' principle, carry away a very large amount of heat, and, accordingly, boilers and hot blast stoves have been interposed in the course of the current, between the furnace and the atmosphere, for absorbing and utilizing this excess of heat. An arrangement of this character is that in which the flame and gases pass through the flue of a vertical boiler forming part of the stack; and another in which the products of combustion pass under a boiler placed on the same level as the puddling furnace.

CHAPTER VIII.

MALLEABLE IRON—*Continued.*

123. Mechanical Treatment of the Puddled Ball.—The puddled ball, as it is withdrawn from the puddling furnace, consists of a spongy mass of malleable iron, of which the particles are imperfectly welded together, and intermixed with much tap cinder; for the expulsion of this latter with the consolidation of the metal, the puddled balls from the furnace are transferred, while still at a welding heat, to *shingling* or *blooming* machines, where the ball is fashioned into oblong slabs called *blooms*, which blooms still retain sufficient heat to permit of their being drawn into rough bars known as *puddled bars*, by passing them through grooved puddling rolls. The operations to this stage are conducted in the *forge*, the subsequent treatment of cutting up, piling, welding, and rerolling for merchant iron, etc., being conducted in the *mill.*

The machines for compressing or working the puddled balls are of two classes, according as the force applied is concussive or compressive; to the former belong the various types of hammer, to the latter belong the class of squeezers.
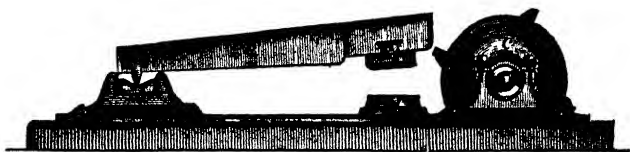
Fig. 32.—Shingling Hammer or Helve.

124. Shingling.—Of the numerous appliances for shingling the puddled ball, amongst the oldest is the shingling

hammer or *helve*, sketched, fig. 32, in which an arm or lever *a* is supported at one extremity upon a pivot bearing *b*; the opposite extremity forming the head being lifted by cams upon a revolving wheel *c*, and allowed to fall by its own weight, through a lift of from 16 to 20 inches, upon the puddled ball placed upon the anvil *d*. The helves are made of several tons in weight, and make from 70 to 100 strokes per minute. The variety known as the *belly helve*, in which the cam is placed below the floor, and acts upon the lever about midway between he head and the fulcrum, gives more space around the anvil than the first description.

Steam hammers are employed for shingling in many of the newer works, replacing the older helve and tilt hammer, the power of adjusting the blow to the condition of the bloom, which is possessed by the steam hammer being especially desirable, while the helve always delivers the same weight of blow under all conditions of the bloom. The steam hammer consists of an inverted steam cylinder *a*, supported upon the standards *c, c*, and fitted with a piston, with its connected piston-rod passing through a packing in the lower cylinder cover; the extremity of the piston-rod is attached to the hammer block or *tup b*, which moves between vertical guides on the standards *c, c*. Steam hammers are called *single* or *double* acting, according as the steam is only applied on the under side of the piston for lifting the hammer head with the piston, which is then allowed to fall by its own gravitation upon the work placed on the anvil, or as the steam acts both in lifting the hammer head with the piston, and also in forcing it down upon the work; in the latter case the acceleration of the falling head is increased by the pressure of the steam above the piston. The puddled ball is placed upon the anvil *d*, the foundations for which in the heavier hammers are upwards of 100 tons in weight. The workman gives motion to the hammer by moving the handle *e*, by which steam is admitted from the boiler to the cylinder *a*, through a suitable slide valve; and the shingler, whose legs and feet are faced with sheet-iron casings, and his face protected by an iron gauze, moves the ball on the anvil between each stroke of the hammer, showers of slag and

scoriae being ejected from the puddled ball at the first few strokes of the hammer.
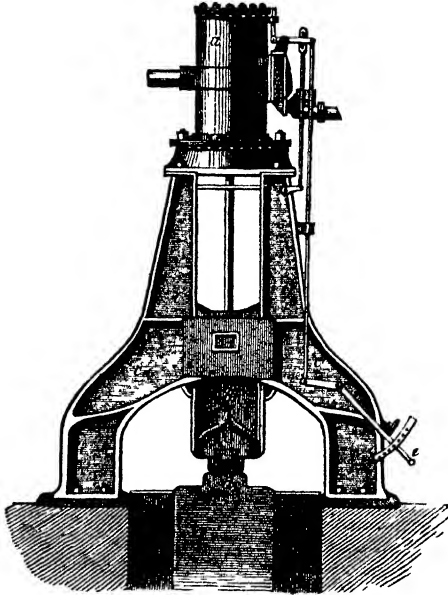
Fig. 33.—25-Ton Steam Hammer.

In Condie's hammer the piston is fixed, and the cylinder carrying the hammer head, block, or tup, moves up and down between vertical guides at each stroke of the hammer.

Squeezers are of various forms. The *alligator* or *crocodile squeezer* consists of a pair of jaws, the lower of which is fixed, while the upper one is opened and closed upon it by a crank and connecting rod, receiving their motion either direct from an engine, or through a heavy fly-wheel connected therewith; the upper or movable jaw is sometimes serrated so as to take better hold of the puddled ball, which is first inserted at the wide end of the jaws, and as its size is diminished from the welding together of its particles and

expulsion of the liquid slag, it is rolled by the shingler to the back part of the jaws, where it becomes more consolidated from the greater pressure applied. In some arrangements of this apparatus the squeezer is made double, that is, having a pair of jaws on each side of the centre or fulcrum, as in fig. 34.
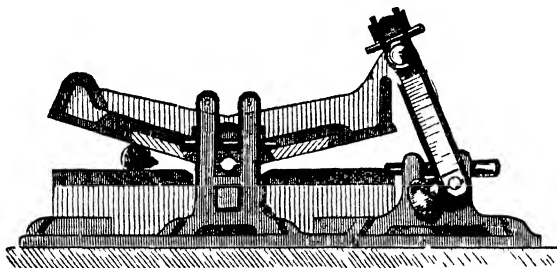
Fig. 34.—DOUBLE SQUEEZER.

The horizontal squeezer consists of a revolving box a projecting about 2 feet above the surface of the masonry in which the machine rests, and is placed eccentrically with regard to an outer fixed box b embedded in the masonry; thus the ball introduced at the widest part d, is carried round by the rotation of a from the larger to the smaller portion e, where it emerges as a puddled bloom ready for the rolls; motion is imparted to the inner or revolving box from a bevel wheel and pinion beneath the apparatus.
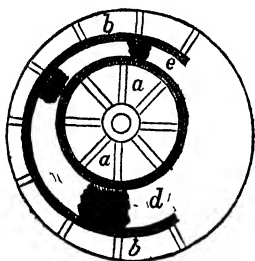
Fig. 35.—HORIZONTAL ROTARY SQUEEZER.

Of the *vertical* squeezers, the most perfect is that of Mr. Brown, which is capable of doing a large amount of work; but the difficulty of maintaining it in working order has prevented its extensive adoption. The squeezer consists of a series of rollers b, b, shaped as in the accompanying figure, the journals at their extremities resting in bearings in cast-iron frames or standards a, a; they are driven by spur gearing

as shown, and by means of the screws l, l, l the rolls can be set at any distance apart. A ball a (fig. 36), introduced at the top is gradually compressed between the rollers as it is carried downwards, where the bloom falls on a Jacob's ladder, and
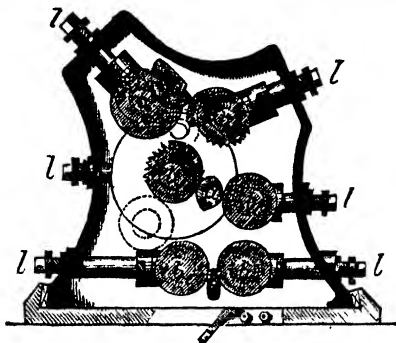
Fig. 36.—BROWN'S SQUEEZER, FOR SQUEEZING PUDDLED BALLS.

is conveyed to the puddle rolls. The figure shows the machine with rollers, to give the ball three compressions, but by inserting other rolls the ball is made to receive a greater or less number of compressions before reaching the bottom of the machine.

125. Rolling Mills.—The shingled bloom, if intended for the production of merchant iron or other bars, is passed while still at a high temperature to the puddle rolls, or, as it is called, the *forge train* or *mill*, where it is rolled into bars some 16 feet in length and 3 inches wide by $\frac{3}{4}$ inch thick, called then *puddled bars*, or if intended for plates or sheets, the bars are made from 6 to 15 inches in width. The forge train consists of two pairs of cast-iron rolls of from 15 to 18 inches in diameter, placed in one line. The left hand pair, called *roughing rolls*, have turned on their surfaces a number of angular or Λ form grooves, diminishing in depth from left to right, and in order to better seize hold of the bar or bloom on its entry between the rolls, the surface of the grooves is usually roughened. In the right hand pair or *finishing rolls*, the grooves, instead of being angular are flat, as shown in the following sketch; the
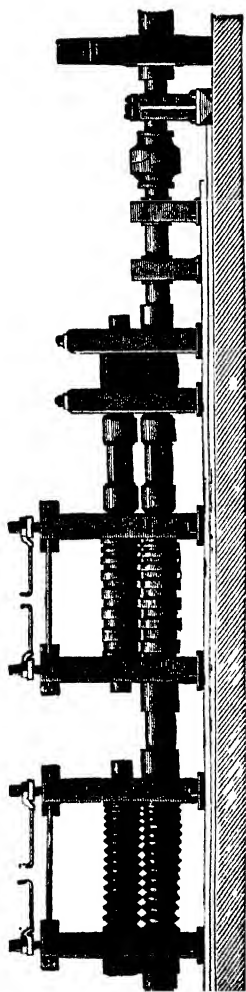
Fig. 37.—FORGE TRAIN OR MILL, FOR ROLLING PUDDLED BARS.

grooves in the top and bottom rolls of each set coming together, and jointly producing the section of the finished bar. The two rolls of each pair revolve at the same speed, which in the roughing rolls is from 60 to 75 revolutions per minute, and in the finishing rolls, 80 to 100 revolutions per minute; the bottom roll is connected directly to the steam-engine, while the top one is driven by a spur wheel gearing into a wheel of the same size on the lower roll, the distance apart of the rolls being regulated by the screws passing through nuts in the top of the standards or *housings*.

The bloom is first inserted into the extreme left hand groove of the roughing rolls, and the slab so obtained is returned over the top of the rolls for insertion into the next groove towards the right, unless the rolls are provided with a reversing motion for altering the direction of rotation at each passage of the bar, when it may be introduced into the next groove without drawing it over the rolls. The bloom is passed in this manner from left to right through both series of rolls, the bar so produced being known as *puddled bar*, or No. 1 iron; for conversion into No. 2, or merchant iron, it requires further working, for which pur-

pose the puddled bar is cut into lengths, piled, reheated, and again rolled. A *pile* consists of a number of bars arranged so as to form a pile or stack, of from 2 to 3 feet in length, and from 6 to 8 inches square, the pieces forming it being arranged so as always to break joint; the pile so formed is held together by a band of iron, and the mass is raised to a welding heat in a reheating or blooming furnace, when it is again passed through grooved rolls, in the rolling mill, similar to those last described, whereby the pressure of the rolls welds the bars into one mass, at the same time reducing its section and drawing it out in length; the rolling is continued until the bar has assumed the required dimensions, or has become so far cooled as to require reheating before rolling further. For No. 3 iron, this process of piling, reheating, and rolling is again repeated, and so on for the higher qualities. Sometimes the welding is effected partly by hammering and is finished only in the rolls.

For plate rolling, instead of grooved finishing rolls, plain cylinders are employed, the pile being built up in a special manner, and passed through the rolls, first in one direction, and then in a direction at right angles to the former, so as to widen out the plate and render the plate more uniform in strength in the two directions. In mills for rolling armour plates and other heavy work, in order to avoid the difficulty of returning the work over the rolls, they are always fitted with reversing gear, by which the rolls can be made to rotate in the opposite direction; but, instead of reversing the rolls in mills for small light work, running at a high velocity, the *three high rolls* have been adopted, in which three rolls are employed, the centre one being driven from the engine, while the top and bottom ones are driven from the middle one by spur gearing; in this manner the work may be passed from the one side between the middle and the top roll, and returned back between the middle and lower roll; while for raising the work from the lower to the higher level, or *vice versâ*, as required at each passage of the work, a lift moving in vertical guides, and balanced by a counterweight, is placed in front at each side of the rolls, actuated either by a lever, a single acting engine, or a hydraulic cylinder and ram.

In the manufacture of the *slit rods* used for wire drawing

and in nail making, a sheet of metal is cut into rods of square or rectangular section, by passing it through special rolls, on which collars are formed, either by suitably grooving the rolls or placing on them steel discs separated by stops, the collar on one roll working into the space on the opposite roll, but still leaving sufficient space between the periphery of the collar and the bottom of the groove for the rod to pass through; in this manner the rolls form a kind of compound shearing or clipping machine, by which the sheet is divided into a number of rods.

In rail rolling, the top and bottom slabs of the pile are formed of No. 2 iron, between which are placed puddle bars; the pile so formed is heated, welded by hammering, and then rolled as in the previous cases, except that the rolls are grooved so as to finally produce the section of the finished rail, and the rolling is so conducted that the top and bottom plates of the rail pile are made into the heads or part of the rail subject to most wear. The rail so produced is then cut while hot to its proper length, by a saw running at a high velocity.

126. Low Moor Iron.—For the production of the best qualities of Yorkshire iron, as that of Low Moor, Farnley, and Bowling, a special method of treatment is pursued; the pig, as already noted, is first refined, broken into small pieces, and then puddled in small charges, with the employment of a somewhat higher temperature than ordinary; the puddled balls produced are shingled under a helve hammer, and formed into plates or slabs called *stampings*, of $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in thickness, and 10 or 12 inches square, which slabs are then broken by the *guillotine* (a weight which is raised up and allowed to fall from a considerable height); the pieces so obtained are carefully assorted and classed according to the fracture, to be used for the production of hard or softer varieties of iron. The selected slabs are then piled together, heated, and welded under the hammer, the masses produced being reheated and rehammered two or three times, the rolls being here only employed in the last stages for giving to the bars their proper shape and section.

In the manufacture of axles, shafts, and bars of large size,

the iron is *faggoted;* that is, a number of small bars are bound together into a bundle, which is then heated in the reheating furnace and welded into one mass under the hammer, when if their form allow, they are finished by rolling.

127. Reheating Furnaces. — The furnaces employed for heating the piles or stamps, described in the last paragraphs, are of several classes: (1), the *open fire* used where malleable iron is produced in the finery; (2), the *hollow fire* as used in South Wales; and (3), the *reverberatory reheating furnace* most generally adopted. The furnaces of the first two types are described under the finery and South Wales processes respectively; and of the latter or reverberatory type, there are two classes, one of which employs coal and solid fuels directly, while the other is heated by the combustion of gaseous fuels.
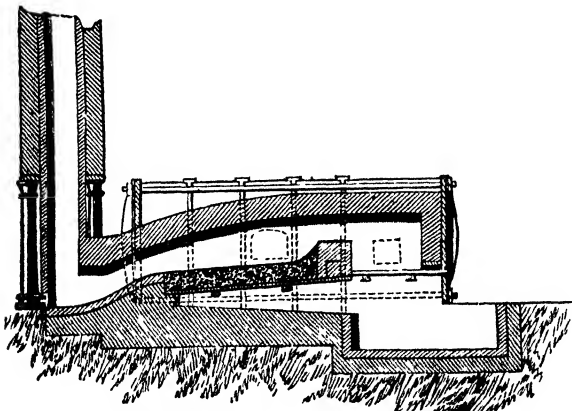
,Fig. 38.—REHEATING OR MILL FURNACE.

The *reheating* or *mill furnace,* in which coal is employed as fuel, resembles the puddling furnace in external appearance and form, the essential difference between the two consisting in the smaller proportion of the fire-grate to the hearth, and in the construction of the bed of this furnace; the bed of the reheating furnace is formed of fire-brick, coated with sand rammed well in while moist, and slopes uniformly from the

fire-bridge to the flue, so that the *slag* or *flue cinder*, produced by the combination of the sand with the oxide of iron or scale formed by the oxidation of the metal in the furnace, may run down to the bottom of the flue and there escape through a tap-hole for that purpose, a small fire being often maintained outside the stack and in front of the tap-hole for preventing its stoppage by the consolidation of the cinder. Like the puddling furnace, the stoking door is stopped with coal, and the draught is controlled by a stack surmounted by a damper; in furnaces for heating bars of ordinary sizes, the roof is kept very low, but its height is controlled by the special conditions of the work. In furnaces for heating large plates and long heavy bars, it is usual to place a second fire-place near the flue, and at right angles to the principal one. The furnace is supported externally by cast-iron plates, connected by tie rods over the top of the furnace.

Of reheating furnaces employing gaseous fuel, the most important are those of Dr. Siemens, which in construction differ from the Siemens furnaces, already described, only in the construction of the bed.

In Austria and Hungary a gas furnace using wood as fuel, has three hearths between the *generator* and the stack; the first hearth, or that nearest the generator, is heated by the sensible heat of the gases therefrom, and is used as a *reheating furnace;* while in the second or puddling hearth, the combustion of the gas is effected by the introduction of air over the fire-bridge; and in the third, heated by the gases leaving the puddling hearth on their way to the stack, is placed the pig-iron for preliminary heating before passing on to the puddling hearth.

The *cinder* or *mill furnace slag* produced in the reheating furnace is essentially a tribasic silicate of iron, containing from 50 to 60 per cent. of ferrous oxide, or from 45 to 50 per cent. of metallic iron, with about 30 per cent. of silica, and smaller proportions of ferric oxide, manganous oxide, alumina, lime, magnesia, sulphur, and phosphoric acid.

The loss of iron in the conversion of pig-iron into bars of malleable iron, varies with the kind of pig operated upon, with the skill of the workman, and the kind of iron produced, that is, upon the number of reheatings to which it is sub-

jected. In Staffordshire the loss averages about 25 per cent. of the pig-iron, and in South Wales it is somewhat greater.

CONVERSION OF PIG-IRON INTO MALLEABLE IRON IN OPEN HEARTHS IN CONTACT WITH THE FUEL.

The reactions involved in the conversion of pig-iron into malleable iron in open hearths do not materially differ from those described for the puddling process, though the furnaces employed and the practical manipulation involved differ much in detail ; the essential differences between the two methods consist in the use of raw coal with the *fining* of the metal out of contact with the fuel in the puddling process, whereas in the present processes *coke* or *charcoal* alone are the fuels employed, and the *fining* takes place with the fuel and metal on the same hearth.

128. South Wales Process.—This process, classed sometimes as a variety of the *Walloon process*, is employed in South Wales for the production of a superior quality of iron, required for the manufacture of the so-called *charcoal plates*, used in the production of tin plate ; and for this purpose pig-iron smelted with cold blast is also employed.

The furnaces employed consist of a small *refinery* or *running out fire*, about 18 inches square, and supplied with blast by a pair of twyers; and two *charcoal fineries*, which are placed in front at a slightly lower level than and connected by inclined channels with the refinery. The refinery has been already described (p. 113), and the charcoal finery here used is a rectangular hearth formed of cast-iron plates, provided with a single slightly inclined twyer using cold blast, the whole surmounted by a chimney or stack. The hearth has three sides vertical, while the fourth or working side slopes a little outwards, and the bottom plate is kept cool by a current of air passing beneath it.

The charge of 5 or 6 cwt. of pig-iron is introduced into the refinery, melted down under coke, and refined to a certain extent by blowing in atmospheric air as previously described, when the imperfectly refined metal is tapped out from the bottom of the hearth along the gutters or channels into the two

fineries, which have been freed from all residual matter, and are still heated from the working off of the last charge; the slag from the running out fire being excluded from the fineries as much as possible. The charge of the refinery is thus divided between the two fineries, when a layer of slag quickly solidifies on the surface of the metal and is removed, after which charcoal is thrown on the top, the blast turned on, and the partia'ly solidified metal broken up; the materials being heaped on the twyer side, where water is thrown on at intervals to prevent the burning away of the charcoal, of which more is added as required to replace that consumed ; the metal is continually raised and broken up by the workman, and the residual ball of metal collected from the hearth after the working of the last heat is added to the charge.   The slag is tapped out two or three times during the process, which lasts a little over an hour, when the metal is collected into a lump, enclosing much interspersed slag or cinder; the lump

Fig. 39.—CHARCOAL
FINERY (*Percy*).

so obtained is hammered under the *helve* into a bloom, and drawn under the hammer, or rolled into a long slab of from 1½ to 2 inches in thickness, which is then nicked partially through and broken with a sledge hammer into pieces of about 25 lbs. each, called *stamps*.   About three of these stamps are placed on a staff, the end of which is made of the same metal as the stamps, the pile so formed being reheated in the *hollow fire*, and welded under the hammer, when the piece thus produced is nicked on its under surface, turned upon itself, again heated in the hollow fire, and rewelded; in this manner or the method of "tops and bottoms," as it is called, both surfaces of the plates are obtained alike, the bloom so obtained being sent to the rolls for the production of sheet-iron.

The finery cinder produced in this process, especially towards its termination, is highly basic containing upwards of 75 per cent. of ferrous oxide (FeO.)

129. The Hollow Fire.—The hollow fire, in which the *stamps* are reheated for welding, is a rectangular chamber without stack; its bottom is formed of cast-iron plates beneath which is an air passage for keeping it cool, and the plates are covered on their upper or working surface with a layer of fire-brick. Coke is the fuel employed, which is placed on the bottom of the chamber through an opening or stoke-hole in the end of the furnace, its combustion being maintained by a blast introduced near the top of the fuel by a twyer inclined slightly downwards; in this manner the upper portion of the chamber is filled with flame, in the midst of which the stamps supported on the staff are inserted, and become heated without coming into contact with the fuel; the flame always escapes more or less around the working door in front of the furnace, but the greater portion of the waste flame is conveyed through an opening in the division wall into a second chamber, where the pile undergoes a preliminary heating before introduction into the hollow fire.

130. Swedish Lancashire Hearth.—The *charcoal finery*, employed in Sweden under this name, consists of a rectangular chamber or hearth, arched over at the top and communicating by a horizontal flue or heating chamber with the stack of the furnace; the hearth is formed of cast-iron plates, and has one twyer delivering a blast heated to about 100°C., or 212°F., by passing it through a tube heated by the waste gases. The hearth being charged with charcoal, the charge of about 2 cwt. of pig-iron is drawn from the flue where it has been placed for a preliminary heating on to the bed of the furnace, when the blast is turned on and more charcoal added. During fusion the highly carburized metal liquates out, and in dropping down before the blast becoming partially decarburized, collects in the bottom, and there slightly hardens, the workmen continually breaking it up and bringing it before the twyer, by which the decarburization or fining is completed; as the process proceeds, the mass becomes less fusible, when the whole is raised to the top, fresh charcoal

added, and the heat increased in order to melt the metal thoroughly, for the better separation of the slag and the collection of the metal into a ball, which is then taken out and shingled, the bar so produced being cut into pieces, which are reheated in a separate furnace, welded again, and further treated under the hammer or by rolling.

131. Walloon Process of Sweden.—This process is somewhat famous as being that by which the celebrated Dannemora irons, so extensively used in the manufacture of best classes of steel, are manufactured. The furnace employed is a charcoal finery using cold blast; the hearth, a rectangular cavity bounded by cast-iron plates lined with charcoal, is characterised by having no tap hole for drawing off the slag, the ball being always worked in a bath of slag, for supplying which finery scraps and hammer slag are melted down on the hearth at the commencement of the process. The iron employed is white or strongly mottled, cast in pigs or slabs some 16 feet long and about 3 inches in thickness, which—the fire being lighted, the hearth full of charcoal, and the blast let on—are placed over the back plate of the hearth, the fore-end of the pig only being inserted into the hearth over the twyer, and as the end melts the slab is pushed gradually forward until the whole charge necessary for the production of a bloom of about 100 lbs. has been melted; the charge is continually worked or rabbled from the time the pig begins to melt to the close of the process, which occupies only about thirty minutes, the iron "coming to nature" very readily. Each lump or bloom produced is drawn out under the hammer into a bar, during which process it requires reheating from six to eight times, of which the first heat is effected in the hearth of the finery itself by holding the bloom with a pair of tongs in the fore part of the hearth during the melting down of the pig-iron for the succeeding charge; the subsequent heats are, however, effected in a separate fire. The working of this hearth is attended with a very large consumption of fuel (charcoal), with the maintenance of a higher temperature than is attained in other charcoal fineries, while the loss in the conversion of the pig into malleable iron amounts to about 20 per cent. of the pig-iron employed.

CHAPTER IX.

STEEL.

The combination of iron with from 0·3 per cent. to 1·8 per cent. of carbon and known as steel, or, as defined by Mr. Holley in a lecture before the Stevens Institute, U.S., as an alloy of iron which is cast in a fluid state into a malleable ingot, has a bluish-grey colour, with a tinge of brown; in cast-steel, it is usually considered that the *bluer* the shade in colour the better the metal; when hardened, it is whiter than in its soft condition. The *fracture* of a steel ingot of a *hard* temper should show a shining silky appearance, not dull and leaden looking, nor containing bright specs embedded in a dull matrix. Steel is void of the fibre so characteristic of wrought or bar iron; its *specific gravity* is from 7·6224 to 7·8131 (Karsten); it is softer than speigeleisen but harder than bar-iron; is very malleable when hot, but requires working at a lower heat than wrought-iron, with the exercise of greater care than is necessary with the latter; it expands less than cast-iron under the influence of heat and can be welded at a lower temperature than suffices for malleable iron, requiring, however, greater attention that the surfaces be freed from scale or oxide by the use of borax instead of the sand used in welding wrought-iron. Its *melting point*, about 1800°C., is between that of pig-iron and malleable iron; it is less easily magnetised, but its magnetism is more permanent than pure iron; it is less oxidizable on exposure to air and moisture than is malleable iron. The *tenacity* of steel varies much with the temper; soft Bessemer or crucible steel will break under a load of from 34 to 40 tons per square inch of section, while the steel used for engineer's tools requires a force of 70 tons or upwards per square inch to break it; and the *power of elongating* before fracture in the milder varieties

is not inferior to that of malleable iron; strips of steel boiler plates $\frac{5}{8}$ inch thick and 3 inches wide, may have a $\frac{5}{8}$ inch hole drifted to $2\frac{1}{2}$ inches in diameter without cracking the plate; while in *elasticity*, steel is superior to malleable iron. The strength and ductility of steel are improved by hammering, rolling, and wire-drawing, if these operations be conducted at suitable temperatures. The most characteristic and at the same time most important quality for many purposes to which steel is applied, is the facility with which the harder tempers may be *hardened* by heating and suddenly cooling, as by immersion of the heated metal in cold water, etc.; the more quickly the cooling is effected, the harder does the steel become; if plunged into oil, which does not act so rapidly in cooling the metal, it is but slightly hardened, but its tenacity is sensibly increased; while by immersion in mercury, or other good conductor of heat, the steel is rendered intensely hard. The metal after hardening is *slightly increased in volume*, and its specific gravity is accordingly reduced, the specific gravity in the hardened state varying from 7·55 to 7·75 (Rinman); in its soft or unhardened condition, if treated with hydrocloric acid it leaves a graphitic or carbonaceous residue, while the same steel in its hardened state is wholly dissolved under the like treatment. By heating to redness, and then allowing to cool slowly, *i.e.*, "*annealing*" of hardened steel, it is restored to its original condition of softness and malleability; thus by hardening and subsequently heating to a temperature below redness, and then suddenly cooling by immersion in water when the steel has acquired the desired temperature, it may be obtained of various degrees of hardness, this operation being known as "tempering" the steel, or in the workshops "letting down;" if the surface be polished and this operation of reheating performed with access of air, films of oxide form on the surface of the steel giving rise to a regular succession of colours, as the temperature rises or falls; from these colours the workman determines the temperature or *temper* of his work; the shades which successively appear as the steel is gradually heated are light straw colour, dark straw, golden yellow, brown, purple, violet, and deep blue; the first corresponds to a temperature of about 220°C., giving the hardest temper, such as is required

in tempering razors, etc., while deep blue, or the temper given to saws, corresponds to a temperature of about .320°C. Articles of steel that require tempering are forged and finished working while in their soft state, and subsequently tempered.

As steel approaches in physical characters to the nature of malleable iron on the one hand, or pig-iron on the other, so the chemical qualities tend to similarity with those of these limits. In *mild* steel, the carbon may not exceed 0·3 per cent., malleable iron frequently containing 0·25 per cent.; and with this amount of carbon it may be welded almost as easily as iron, and can be worked under the hammer at nearly the same temperature as is used for malleable iron; while the *harder* tempers of steel, containing 1·5 per cent. of carbon, are more brittle, require to be hammered with great care and at a comparatively low temperature, thus approaching towards cast-iron in behaviour. The hardening quality of steel seems to depend upon its state of carburization; for steel containing less than 0·5 per cent. of carbon does not sensibly harden except in very small thin pieces, and the higher the carburization the lower the temperature at which the steel will harden. Pure iron will not harden even if plunged into mercury. Silicon, present in certain varieties of pig-iron to a large extent, occurs but to a very limited amount in steel, the presence of 0·5 per cent. of this element in steel rendering it almost unworkable at a red heat.

132. Alloys.—Steel alloys readily with many other metals; *copper*, in not too large proportion, alloys readily with steel, with the production of a substance harder than steel, but which is also red-short.

Tungsten alloys with steel in all proportions, the product is said to be harder and more elastic than ordinary steel; it requires, however, considerable care in its production.

Manganese, in some form, is now almost universally used in the manufacture of steel; as speigeleisen or carbide of iron and manganese, it is an essential element for the success of the Bessemer process, and it is also said to render the ingots sounder and more free from honeycomb. The action of manganese in improving the quality of steel is by no means determined, for it would not appear to depend upon

the formation of an alloy of manganese and steel, since the former body passes almost wholly into the slag, a small proportion only entering into the composition of the steel; still, that the presence of a small amount of manganese is necessary is shown from the fact, that the metal which has been remelted without a further addition of manganese (and in which the residue of manganese has been removed in the second slag or flux), is found to be *red-short*, while, if a little manganese be added to the charge in the remelting, the quality of the metal is not deteriorated by the second fusion.

The use of *titanium* in steel is the subject of numerous patents, it is said to give "body" to the steel, that is, the quality of retaining its hardness *without* brittleness after repeatedly reheating; its use is however questionable, and I have been unable to detect titanium in some specimens of the so-called titanic steel. Steel will only alloy with very small proportions of *silver*, and if melted with considerable quantities of silver, the latter almost wholly separates on cooling. *Gold, platinum*, and *aluminum* alloy readily with steel, though the resulting alloys have had but little practical application. *Aluminum* was once considered to be the peculiarity of the fine Indian steel known as "*Wootz*," which received such a fine damaskeened surface; this view, however, is now discredited.

Sulphur, phosphorus, and *copper* are the great enemies of good steel, 0·2 per cent. of sulphur rendering the metal *brittle* and *red-short*, while 0·1 per cent. of phosphorus is objectionable as tending to render it unworkable at ordinary temperatures, *i.e.*, *cold-short*, and 0·5 per cent. of copper induces *red-shortness* in the steel.

133. Damaskeening is the name applied to the method of producing the brown colouration and figuration· of gun-barrels, sword-blades, etc.; it is produced by the action of various acid solutions on the metal, and is considered to be due to the unequal corrosion or solvent action of the liquid upon ·the metal, with the deposition of films of carbon, etc., on various parts.

134. Methods for the Production of Steel.—The production or manufacture of steel may be classed under the following heads :—

I. Methods of *producing steel direct from the ore*, as in the Catalan forge, or by heating rich ores, as oxides, with carbon or carbonaceous matters in crucibles or suitable furnaces.

II. By the *carburization of malleable iron* by solid or gaseous carbonaceous matters, as in the *cementation* process, or in the production of cast-steel in crucibles or other vessels.

III. *Decarburization methods*, divisible into the following classes, viz. :—

1° By the partial decarburization of pig iron in the finery, puddling furnace, or other apparatus.

2° By the fusion of pig-iron with oxide of iron, etc., as in the **Uchatius' Process**, etc.

3° By the fusion of pig-iron with malleable iron, the **Siemens-Martin** process.

4° By the **Bessemer** or *pneumatic* process.

DIRECT METHODS, OR PRODUCTION OF STEEL DIRECT FROM THE ORE.

135. Steel in the Catalan Forge. — The Catalan forge has been already described (p. 107), and it is only requisite, if steel is to be the product instead of malleable iron, that the decarburization be not carried so far ; for which purpose the inclination of the twyer is diminished, and so the reduction of the ore is effected more slowly, allowing the reduced metal to remain for a greater length of time in contact with the fuel (charcoal), whereby an amount of carbon is introduced into the metal sufficient to constitute the product, *steel*

This process, as also all those for producing *natural steel*, as practised in Styria, Westphalia, and other parts of the south of Europe, known as the Styrian, Carinthian, and other processes, are rapidly being replaced by the more modern methods of steel manufacture, and will not require further notice.

136. Chenot Process. — This process consists of two stages, viz. :—

1° Fusion of the ore in a particular manner, for the production of a metallic sponge.

2° The fusion of this spongy mass with solid hydrocarbons, or after its saturation with liquid hydrocarbons.

The metallic sponge is prepared by breaking the ore into lumps about 30 c.c. in size, which are cemented together by pressing them with about 3 per cent. of resin, and the ore so prepared is mixed with more charcoal than suffices for the removal of the oxygen in the ore. This mixture is introduced into a furnace about 50 feet high, consisting of two vertical retorts contained within a conical covering, vertical flues conducting the gases and flame from the fire along the vertical sides of the retorts; the reduction is completed in from three to five days, when the charge is withdrawn by removing the bars at the bottom of the retorts, and allowing the mass to fall into receivers placed on waggons beneath their lower extremities. The receivers or coolers can be closed so as to prevent the access of air until the mass has cooled down, which may be promoted by circulating water around them. The *metallic sponge*, or pulverulent matter so obtained, is mixed with charcoal powder or solid matters rich in carbon, or saturated with liquid substances rich in carbon but free from sulphur; the mass is then compressed to about two-thirds of its original bulk and melted in crucibles, when the gangue of the ore rises to the top of the melted metal, and is cooled immediately before teeming by throwing in a little sand, when it may be skimmed off. This process has been found unprofitable in Sheffield, since the Chenot charge, though smaller than an ordinary crucible charge, requires the same quantity of coke for its fusion.

137. The Siemens Direct Process.—Dr. C. W. Siemens, F.R.S., has adopted the principle of his regenerative gas furnace to the production of wrought-iron or steel direct from the ore. The furnace he now employs is a rotatory furnace, connected with his gas producers and four regenerators of the ordinary construction to each rotator. The *rotator*, or revolving cylindrical chamber with truncated ends, is about 7 feet 6 inches in diameter and 9 feet long, is constructed of iron, and rests upon four anti-friction rollers; it is connected with gearing by which varying speeds of rotation can be communicated to it, and is lined with *bauxite*, a very refractory mineral, consisting chiefly of alumina and ferric oxide with small quantities of silica; for which purpose bricks are made of calcined bauxite, mixed with

3 per cent. of clay and about 6 per cent. of plumbago. The chamber being lined with these bricks is raised to a high temperature, and their surface glazed by the introduction of cinder or slag-forming materials, whereby the lining is protected from the further action of the flame. Beneath the working door, situate at one end of the chamber, is the tap-hole by which the slag is tapped out into vessels placed in a cave beneath the rotator, whilst the opposite end of the rotator is in communication with the regenerators, of which there are two pairs to each furnace, which serve respectively for the introduction of the heated gases and air, and for the withdrawal of the products of combustion from the chamber; a brick partition constituting the only division between the entrance and exit flues, the velocity with which the gases are introduced being sufficient to carry them to the working door before being drawn back into the exit channels, which are at the same end of the chamber as the openings by which the gases are introduced.

The furnace having been heated and set slowly revolving, the charge of ore broken into fragments of the size of beans, along with lime or other fluxing materials necessary for the production of a liquid slag, is introduced ; the gas and air are turned on, and the charge becomes heated to bright redness, when small coal of uniform size to the amount of about 20 per cent. of the charge of ore is introduced, after which the velocity of rotation is increased to facilitate the mixture of the charge. Decomposition ensues, the ferric oxide is reduced to magnetic oxide, which, on its beginning to fuse, causes the decomposition to become more violent ; at the same time some metallic iron is separated and a liquid slag also produced. During this stage the velocity of the rotation is diminished, and the supply of gas is almost entirely shut off, heated air only being admitted for the combustion of the gases produced by the decomposition in the rotator. When the reduction is completed, the rotator is stopped and the slag or cinder tapped off, when, if wrought-iron is the object of the process, a quick speed of rotation is again imparted to the furnace for collecting the charge into balls; projecting ribs on the inner circumference of the rotator dividing the charge into three balls, which are then removed and shingled in the ordinary manner

for the production of puddled blooms.   If steel be desired, instead of collecting the charge into balls and shingling, the balls are either removed direct to a steel melting furnace, or, after tapping off the slag, from 10 per cent. to 15 per cent. of speigeleisen is added, and the gas and air from the regenerators turned on, when the charge is rapidly melted down and may be tapped out into moulds, forming cast-steel ingots.

The reduction lasts about two hours for the production of malleable iron, or two and a half hours for cast-steel, is attended with a very large economy in fuel, and requires but a very small amount of manual labour for the conduct of the process.

PRODUCTION OF STEEL BY THE CARBURIZATION OF MALLEABLE IRON.

138. Cementation Process.—The cementation or converting process consists in the conversion of bar-iron into steel, by the long continued application of a heat approaching to whiteness, or about 1170°C., to bars of iron embedded in charcoal, the whole contained in suitable chests, and kept out of contact with the air.

The converting furnace has externally the appearance of an ordinary glass-house furnace; it consists of two stone or fire-brick boxes or troughs N, N, called *pots*, each from 3 feet to 4 feet in width, about the same in depth, and 12 feet in length, and open at their upper surface.   These pots are arranged one upon each side of the fire-place C, which runs the full length of the furnace, and are contained within the chamber or vault of fire-brick A, covered in by the arch B; beneath and up the sides of the pots are built a number of transverse and vertical partitions respectively, whereby the space along the length of the pots is divided into a number of transverse and vertical flues, so that the gases and products of combustion from the fire circulate under and around the boxes before obtaining access to the flues D,D, and by the short chimneys E,E, with the interior of the dome F, which surmounts and encloses the whole.   There are usually three of the short chimneys E along each side of the vault. G is a man-hole in the brick end of the chamber or vault, large enough to admit of the entrance of a man to charge

the pots and *draw the heat* after conversion is completed; this hole is placed immediately above the level of the top of the pots, and during the converting process is closely bricked
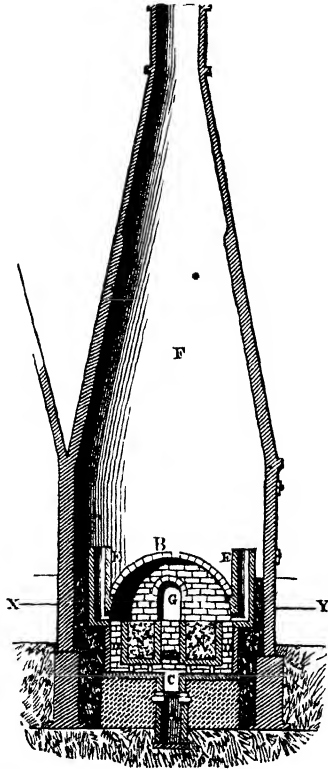
Fig. 40.—VERTICAL SECTION OF CONVERTING OR CEMENTATION FURNACE.

up. Two small holes, called *tap holes*, are left in the ends of the furnace opposite to a corresponding hole in the end of each pot; these are for the insertion of *trial or tap bars*,

that is, bars that are placed so as to allow of their withdrawal from time to time as the conversion proceeds, to examine the progress of carburization in the bars. These furnaces are built in ranges of five or six, or more together.
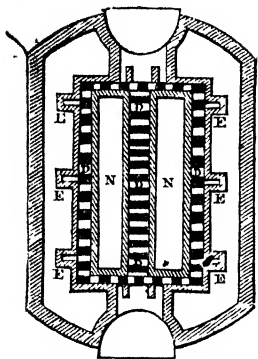
Fig. 41.—Plan of Converting Furnace on Line XY.

The bars for conversion or cementation are from $2\frac{1}{2}$ inches to 3 inches in width, $\frac{5}{8}$ to $\frac{3}{4}$ inch thick, and from 6 feet to 12 feet in length, hammered bars being generally preferred to rolled bars. The pot is charged by placing over the bottom of each a layer of small nubs of charcoal, the charcoal employed consisting of a mixture in about equal proportions of fresh charcoal with that left from a previous charge, after the latter has been freed from the fine dust, etc., which accompanies it on withdrawal from the pots; and charcoal from the harder woods, especially oak, is preferred; on this layer of about $\frac{1}{2}$ inch in thickness is placed a layer of bars, with their flat sides downwards, allowance being made both in length and breadth for their expansion on heating; over the bars again is placed another layer of charcoal, to the same depth as before, then a layer of bars, and so on, alternately charcoal and bars of iron, until the pots are filled, the last layer being charcoal; the surface is then covered over with a thick coating of *wheelswarf*, a mixture of siliceous matter and particles of steel, which collects as a kind of mud in the trough of grindstones, and which, under the heat of the furnace, fuses or frits to a pasty mass of silicate of iron, etc., glazing over the surface and perfectly closing the contents of the pots from the air. The charge for each pot consists of from 12 to 16 tons of bars, though in some cases the furnaces are capable of holding 30 tons of bars. When the furnace is charged, the man-hole is bricked up, the space around the trial bar carefully luted up with clay, and all other apertures made air-tight; after which the fire is lighted, when

in about twenty-four hours the pots are at a red heat, and in about two days have attained the temperature necessary for conversion; the heat is now steadily maintained, and for this purpose a coal (as good white ash coal) which does not clinker, but burns uniformly and regularly, is required. The conversion is continued for a period of from seven to nine or ten days, according to the temper the converted bar is required to possess, the harder the temper the longer the process is required to be continued. The trial or tap bar is withdrawn from time to time, and from its appearance on fracture, the progress of the operation is judged. In the early stages of the process, or when the product would correspond to No. 1 temper or "spring heat," the tap bar on breaking shows a thin layer of white steely material, surrounding a nucleus of comparatively unaffected bar-iron or "sap," as it is called; while, as the process advances, the steely character of the surface gradually penetrates through the mass. In No. 4 temper or "double shear heat," the fracture shows about equal proportions of an inner nucleus and of a crystalline steely exterior, though the demarcation between the two should not be sudden; if it be so, it indicates that the conversion is being carried on too rapidly. In No. 6 temper or "melting heat," the inner nucleus or kernel has entirely disappeared, and the conversion is completed; the change having taken place through the entire mass, the fibrous character of the fracture and blue colour due to bar-iron being entirely wanting. When the change is considered complete, according to the purpose for which the steel is required, that is, has attained the required temper, the fire is either drawn, or more usually allowed to burn out, and the furnace allowed to cool down during three or four days; the man-hole door is then taken down, and after an interval of two days longer, a man is able to enter and the withdrawal of the charge commences.

The bars on withdrawal, instead of presenting the smooth surface and tough fibrous fracture with the bluish colour of wrought-iron, present now a surface covered with protuberances or blisters, varying from the size of a pea to an inch in diameter; the bars are readily broken by the blow of a hand hammer, the fracture presenting a crystalline appearance,

and the bluish tinge has become sensibly browner or yellower than in bar-iron; the specific gravity is also below that of the wrought-iron, and the total product has increased from one-half per cent. to three-fourths per cent. in weight. The bars are now known as "blister steel," or "converted bars." Besides the changes in physical character just indicated, the metal has undergone a marked chemical change; for while the original bar-iron contained not more than ·25 per cent. of carbon, the converted bar will contain from ·5 to 1·5 per cent. of carbon, according to the length of time during which the heat was continued, and the carburization will not be confined to the surface but will extend quite through the mass of the bar.

The origin of the blisters on the surface of the metal has not been clearly accounted for; possibly they may be due to the reduction of the oxide of iron contained in the basic silicate of iron, which is distributed more or less through the bar-iron as mechanically trapped slag, and which by contact with carbon at the temperature required for conversion, suffers reduction, when carbonic oxide would be envolved, which in its efforts to escape while the iron was in a soft condition, might form the blisters on the surface. In the best bars the blisters are tolerably uniform in size, and distributed evenly over the surface, while, if the blisters are irregular in size, and disposed in somewhat definite directions, then there has been a want of homogeneity and regularity in the bars employed. If air has obtained access to the bars during conversion, the bars are rough and have a skin of iron on their surface rendering them difficult to break; *glazed* bars show traces of fusion on their surface, from the temperature of the furnace having been too high. *Aired* and *glazed* bars are unfit for melting into best cast-steel, and require reconverting.

139. Shear Steel.—If the blister steel be cut into suitable lengths, piled together, heated in a hollow coke fire to a welding heat, and forged into a solid bar under the hammer, the bar produced is then known as "single shear steel;" and if this be cut into two parts or doubled upon itself, again welded in the same manner, and drawn into bars, it then forms "double shear steel." To prevent the blister steel

suffering oxidation and decarburization while in the fire, the pile or fagot is dusted over with powdered clay, or sand and borax. The effect of the hammering of the pile or "fagots" has been to render the blister steel (which is never homogeneous) more uniform in composition and texture, and has obliterated all the appearances of lamination which a bar of blister steel exhibits on fracture.

140. Case-Hardening.—This is a process by which the surface of articles made of wrought-iron are superficially coated with a skin or layer of steel. The necessary carburization is effected after the article has received its finished form and dimensions, by heating it to bright redness and, if a small article, sprinkling powdered ferrocyanide of potassium over its surface, when the article is returned to the fire for a few minutes and then cooled by immersion in water; for giving a thicker coating, or for case-hardening larger articles, such bodies are placed in wrought-iron boxes, embedded in substances rich in carbon, as fragments of horns, bones, and leather cuttings; the box is then luted up so as to become air-tight, and is placed in a furnace where it is maintained at a red heat for about twelve hours, when the fire is allowed to burn out, the box removed, and its contents emptied out.

141. Cast or Crucible Steel.—The blister steel prepared by cementation, however much it may be hammered or tilted, unless subsequently fused, is never homogeneous, want of homogeneity arising from the presence of mechanically mixed impurities, as slag, etc., in the original bar-iron, as also from irregularities and fluctuations in the temperature of the different parts of the chest or pot during conversion. Hence, for most purposes, the blister steel is subjected to fusion in crucibles, either alone or in conjunction with bar-iron, carbon, manganese ores, or speigeleisen, when the product is known as *cast-steel*, or homogeneous steel. Cast-steel is also largely prepared by the direct fusion of bar-iron with charcoal and oxide of manganese or speigeleisen, in the manner subsequently described.

The *melting furnace* is the name applied to the part of the building devoted to the melting and casting of the steel. The furnaces contain various numbers of "melting holes" or "fires," arranged along one or both sides of the furnace, the

middle of the floor being occupied by the *teeming holes*, and necessaries for the preparation of the moulds for the reception of the melted metal. The teeming holes are rectangular holes about 3 feet long by 2 feet wide, and of varying depths, in which the ingot moulds are placed so as to allow of the adjustment of their height and inclination for convenience in emptying
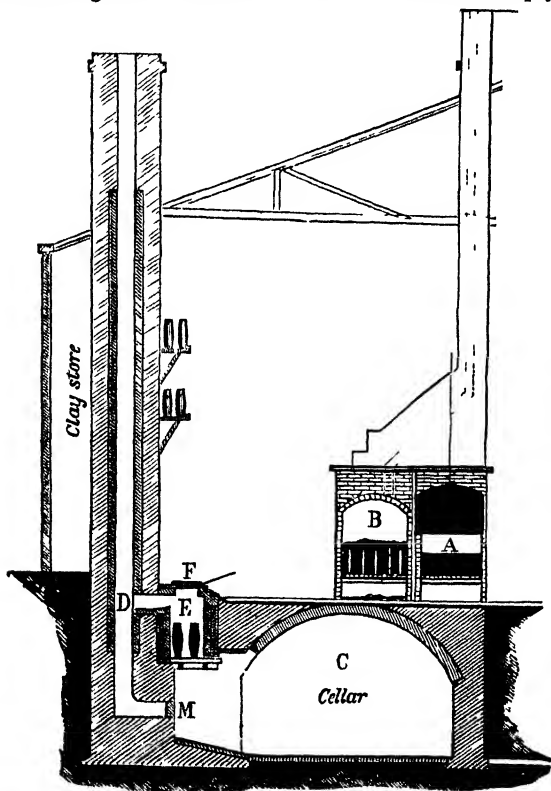
Fig. 42.—Cast Steel Melting Furnace A, Annealing Ovens. B, Annealing Ovens with front Plate removed.

the contents of the pots or crucibles, technically, *teeming* of the metal; these holes are covered over with iron plates, making them level with the floor of the furnace when the teeming is not going on. The *holes* or *fires* E (fig. 42), are simple rectangular chambers of brickwork, about 3 feet from centre to centre of the partition walls; a wall, single brick in thickness, being the only brickwork separating the fires; but each of these "holes" is lined with a coating some 6 inches in thickness, of a refractory material, as "ganister;" for which purpose oval moulds, patterns, or templates of wood (whose major and minor diameters are 26 inches and 19 inches respectively) are prepared, placed on the fire-bars, when slightly moistened ganister is rammed down around them with an iron rammer; the pattern is then withdrawn, leaving an oval cavity E capable of holding two pots or crucibles. The ends of the fire-bars rest upon bearers built in the brickwork, below the level of the roof of the cellar, and so render the bars accessible for withdrawal in case of running pots, etc., from the cellar C, whereby the fire is allowed to fall through into the ash-pit beneath the bars or grate, and so permitting of the extraction of the faulty crucible. Each fire has its own ash-pit as well as its own flue, D; these flues are carried up in groups of five or six together, to form a stack about 40 feet in height; and each one is carried down below the level of the grate-bars as shown, and opens into the ash-pit, allowing of a communication being opened or closed with it by the insertion or withdrawal of a brick from the opening M; in this manner the draught of the fire can be regulated so as to enable the *melter* to have the contents of all the pots or crucibles melted and ready for casting at the same time. The top of the melting hole formed by an iron plate is level with the furnace floor, and closed by a cover F, consisting of a square wrought-iron frame, in which is inserted a slab or quarry of fire-brick, about $2\frac{1}{2}$ inches thick ; to the frame is attached a round iron bar or rod, inclining slightly upwards, and which forms the handle for the removal of the cover. Each fire holds two pots or crucibles, which are raised about 4 inches from the bars by placing each one on a round stand of fire-brick, and when charged, the pots are covered with flat plates or lids made of a refractory material similar to the crucibles.

The crucibles, which are made of mixtures of fire-clays, with ground pots, and coke dust or plumbago, are from 16 inches to 19 inches in height, 9 inches in diameter at the widest part, and from 5 to 8 inches at the mouth; their preparation has been described on page 16. The pots—hot from the annealing oven shown on page 162, and which is built at the end of the melting furnace—are moved by suitable tongs and placed on their own stands in the fire or melting hole, a small quantity of live coals having been previously placed on the grate; the fire is then made up with coke level with the top of the pots, and the heat raised gradually, when in about half an hour they are ready for charging. From fig. 43 it will be observed that the crucibles, on leaving the mould, have a hole through the bottom, and for the purpose of stopping this (on introducing the metal of the charge) a handful of sand is first thrown in, which at the temperature subsequently attained in the fire, frits and closes the hole, the heat at the same time attaching the crucible and stand together, so that on removing the crucible and melted metal from the fire, the stand is always brought out also. Each pot, if a good one, lasts one day of three rounds or melts, with charges of 50, 44, and 38 lbs. respectively.

Fig. 43.—Apparatus employed in moulding the Crucibles in which Steel is melted. *a*, plug; *b*, flask; *c*, trunnion arms; *d*, eye-stud at the top of the plug.

If the crucible charge consists of blister steel, the metal is broken up into small pieces by the hammer, and the charge of from 50 lbs. to 60 lbs. of metal, sometimes with the addition of a varying amount of oxide of manganese, is introduced through a wrought-iron funnel-shaped charger into each pot; the lid is placed on the top of the crucible and the fires are then filled up with coke, which burns off in from forty-five to fifty-five minutes; the fire is then pottered down to allow the coke to pass down to the bottom of the pots and again fired; when this second fire has burnt off, the lids of the crucibles are turned off, and the melter goes over the pots

inserting a rod of iron into them to ascertain if any portion of the metal is still unmelted, and gives instructions accordingly as to the quantity of coke that is to be added to each fire.

If the molten steel be not allowed to remain long enough in the fire, it will throw out sparks or *teem* fiery, and the ingot will be full of bubbles or holes (honeycombed), when the metal is said not to be *killed ;* if it remain too long in the fire it *teems* dead, and the ingot will be of inferior quality.

The pots after teeming are conveyed back to the fires, when after the slag and clinker adhering about their bottoms and sides have been broken off by an iron bar, they are at once replaced in the hole ; after all the pots have been emptied and thus returned to their places, recharging commences ; the *second heat,* as this melt is called, coming down much more quickly than the first ; for while the first heat occupied from four and a half to six hours, the second will be melted in about two and a half hours.

The moulds in which the small ingots of steel are cast are of cast-iron, made in two halves to facilitate the removal of the ingot after casting ; the two halves are held together by rings and wedges, and before using each half of the mould is *reeked,* or covered with a layer of coal-tar soot on the inner surface, to prevent the adhesion of the fluid metal to the mould. When soft metal is cast, it rises or boils up after teeming before coming solid, and a metal stopper is inserted on the top to prevent this action ; if the metal be harder in temper, say containing about ·8 per cent. of carbon and upwards, instead of rising, it will *pipe,* that is, the melted metal settles down, leaving a hollow tube in the top of the ingot, which requires to be broken off (that is, the ingot is topped) before working under the hammer. If a large casting has to be made, the pots or crucibles are all first emptied into a ladle with a fire-clay plug in the bottom, by raising which the steel can be tapped from the ladle in a continuous stream into the required mould ; or, if the large ladle be not employed, two or more teemers may be engaged at the mould emptying pots, so as to keep up a continuous stream of metal, men bringing up the pots with the assistance of *barrows,* and returning them when empty to the *pullers out,* who reinstate

them in the fire. The barrows mentioned consist of a pair of teeming tongs, rather larger than usual, and mounted on a vertical pivot attached to the axle of a pair of wheels, so that a man receives the pot in the bowed jaws of the tongs, then pressing on the handle, the wheels acting as a fulcrum, the pot is raised from the ground, and in this position he then runs it forward to the mould.

The process just described is that of making cast-steel by melting blister steel or converted bars; but the larger quantity of cast crucible steel is now made from unconverted bars, that is, from the bars of malleable iron direct, without the intervention of the process of *converting* or *cementation*; for this purpose the bars are cut by shears into pieces about $\frac{3}{4}$ of an inch square, and charged into the pots in the manner described, except that there is also added at the same time a quantity of charcoal varying in amount from half an ounce to eight ounces per charge, according to the *temper* of the steel to be produced; and after the second fire has burnt off, a quantity of *speigeleisen* (the highly carburized and manganifer-ous pig-iron already described) is usually added, the operation in other respects being the same as that described in the last article. For the preparation of the softer or mildest tempers of steel, instead of adding the charcoal above mentioned, the melting is performed in *black* or *plumbago* pots, that is, in crucibles containing a large amount of plumbago, with only sufficient fire-clay to give the necessary plasticity to the mixture. Steel melted in such pots obtains an amount of carbon from the material of the pots sufficient to convert the bar-iron into steel, with the addition only of from $1\frac{1}{2}$ per cent. to 4 per cent. of speigeleisen; in other respects the operation is conducted as before. For steel that requires to be of a hard temper, but yet capable of welding easily to either itself or to iron, as for certain classes of cutlery, etc., the larger proportions of charcoal are added, with a few ounces of oxide of manganese, while the addition of speigeleisen is not then made. Charcoal prepared from the oak is preferable to that from the softer woods.

For the manufacture of best crucible steel, Swedish bar-irons made from *magnetic ores*, practically free from sulphur and phosphorus, and smelted with charcoal, are preferred;

the irons made from the ores in the district of Dannemora, in Sweden, being especially prized, and command accordingly high prices in the market; ranking next are probably the Persberg irons, also Swedish. Each bar of Swedish iron is stamped with a letter or mark, ceded by the Swedish Government (and registered by the Board of Trade) to the owners of the works where the iron is made; the number of these brands is accordingly almost legion, and it will suffice here to note a few of the more important Dannemora brands. Amongst the *best* marks are :—

(L) hoop L, and OO double bullet.

W and Crown (F) Hoop F, *Middle Dannemora Marks.*

(S) little S. (R) gridiron, *Common Dannemora Marks.*

Numerous chemical *physics* have been, and are still used in Sheffield for the improvement of cast-steel, or the manufacture of best-steel from inferior brands of iron ; of such may be mentioned sal-ammoniac (NH_4Cl), common salt ($NaCl$), common rock salt, nitrate of potash, chromate of potash, prussiate of potash, iodide of potassium, fluorides (will be noticed as the " Henderson " process), manganese now universally used, and numerous alloys of the rarer metals, of which something is said under the head of "Alloys of Iron and Steel."

The addition of iodide of potassium to the crucible charge constitutes the *Sherman process*, and has for its object the removal of the sulphur and phosphorus from the iron, in virtue of the powerful affinity existing between these elements and iodine; chemical analyses and mechanical tests applied by the writer have failed, however, to show any decided advantage from its use.

142. Melting in Reverberatory Furnaces.—The decarburization of the steel and the corrosion of the furnace by the oxide of iron formed, have prevented the adoption of the ordinary reverberatory furnace for the melting of cast-steel; but in France, a series of chambers each holding several pots, and heated by the flame from the combustion of fuel on a

separate fireplace, have been used, the combustion being·
urged by a chimney aided by a blast introduced beneath the
grate.   To overcome the difficulty of oxidation, etc., it has
been proposed to effect the fusion under a slag of bottle glass,
but with the use of solid fuels this process has never been
successful.   The furnace employed in the Siemens-Martin
process is essentially a reverberatory furnace, with the appli-
cation of gaseous fuel from the Siemens generator.

143. Siemens' Melting Furnace.—The Siemens regenera-
tive gas furnace has been applied to the melting of cast-steel in
crucibles, and is reported to effect a considerable saving in the
item of fuel, three tons of coal slack distilled in his generators,
and the gas therefrom subsequently consumed in conjunc-
tion with his regenerators, melting an amount of steel which,
in the ordinary manner, required about seven tons of coke
for its melting.   The gas producer and the regenerators have
been already described (p. 128), and it is only necessary to add
here, that to apply it to steel melting, the pots are placed in
a chamber above the level of and between the two series
of regenerators, leaving an arched vault beneath the furnace
bottom.   The melting chambers are formed of brickwork
arched horizontally and vertically, and strengthened by
cross walls at intervals, and of sufficient length to contain
24 pots or crucibles arranged in pairs; they are 3 feet 6
inches wide at the bottom, and 2 feet wide at the opening
along the top, which is closed or covered by loose fire-brick
covers.   The heated gases and air rise through the heated
regenerators at one side of the chamber, and are drawn
down through the regenerators at the opposite side by the
draught produced by the stack with which they are con-
nected; and by placing the pots on suitable platforms con-
nected with mechanism in the vault or cave beneath the melt-
ing chamber, they can be raised in groups from the furnace
without the labour of removing the pots singly, thereby
facilitating the casting of large ingots or masses of steel.

144. Wootz.—The Hindoo steel which has received this
name, is obtained by treating malleable iron in small unbaked
crucibles, with 10 per cent. of its weight of the leaves and
stems of the *cassia auriculata*, the charge of metal for each
pot being a little over 1 lb. in weight.   The surface of the

charge in the pot is covered by two smooth green leaves of the *asclepis gigantea;* the lid is then carefully luted on, and about twenty of the pots are then arranged so as to form an arch or dome over a small cavity made in the ground, one pot being removed for the insertion of the nozzle of a pair of very primitive bellows, and for the introduction of the charcoal fuel into the pit or recess. The heat is maintained for a period of from two to four hours, when on breaking the pots, a small cake of hard steel, presenting a series of striations on its surface, is obtained from each pot. Wootz is stated to be a superior class of steel, but requiring great care in its working. In some specimens *aluminum* has been detected, but it is not considered to be an essential element of the Hindoo metal.

DECARBURIZATION METHODS FOR THE PRODUCTION OF STEEL.

145. Puddled Steel. — The conduct of this process is essentially the same as the ordinary puddling process for the conversion of pig into malleable iron, except that the *fining* is carried on more slowly, so that although the decarburization is not so complete as in ordinary puddling, still the process usually occupies a few minutes longer for its completion. The slag in this process is required to be more fluid and less decarburizing than when malleable iron is to be produced, and hence the use of a pig-iron containing a large proportion of manganese, such as *speigeleisen*, is desirable for this process, the manganese forming a more fluid and less highly basic slag than when oxide of iron with only a small quantity of manganese, form the bases of the slag.

The operation is conducted in a puddling furnace differing but slightly from the furnace employed for the production of malleable iron, the chief differences being, that the bed is smaller, the area of flue to grate is greater, as also the height of the bridge is some few inches greater than in the ordinary puddling furnace, whereby the grate contains an increased depth of fuel, and so enables the workman to maintain a more powerfully reducing flame when such is required.

The charge of pig-iron is reduced into small pieces as

uniform as possible in size, and from 3 to 4 cwt. is spread evenly over the bed of the furnace, a pretty strong heat being maintained so that it may melt rapidly without unnecessary oxidation; in this stage the temperature is higher than when wrought-iron is produced, and the charge is melted in from forty to fifty minutes; the damper is now closed until the metal thickens and begins to rise, when the mass is rabbled or stirred continuously, the damper being carefully raised so as to maintain the charge thoroughly m·lted, the continued stirring keeping the mass uniformly carburized by the continual passage of the decarburized metal from the surface into the bath of metal below. In from thirty-five to forty minutes from the commencement of stirring, floating granules of metal begin to appear, and from the appearance of these grains is afforded an indication of the quality of steel that is being produced; if the grains are white and brilliant, the metal will probably be uniform and of good quality, but if large and flaky, the steel has a tendency to be coarse and inferior in quality. At this stage the *balling* commences; the damper is again partially closed, whereby the temperature is reduced and the bed or hearth of the furnace is filled with flame of a non-oxidizing character, which is essential in this part of the operation, otherwise either iron or steel with an insufficiency of carbon results. The balling operation requires considerable care and practical skill for its successful performance, and is effected at a lower temperature than when balling wrought-iron; the balls also require hammering or shingling with greater care, and at a lower temperature than malleable iron, especially so if a hard or highly carburized steel has been produced. During the *boiling* and *fining* stages of the operation, the mass presents the same appearance of jets of burning carbonic oxide which appears in the ordinary puddling process; the difference between the two processes consisting in stopping the puddling at a point before complete decarburization is effected, if steel is the product required.

Mixtures of pig-irons are to be avoided in this process, since one kind of pig-iron might probably *fine* and *come to nature*, while the other remained quite fluid and highly carburized, notwithstanding the presistent stirring.

The process as at first introduced into England by Mr. E. Rieppe and practised at the Mersey Steel and Iron Works, was conducted slightly different from the method above described; the charges were smaller, and when the metal began to fuse, forge or mill cinder was added, after which when the charge was fully melted, a small quantity of a mixture of black oxide of manganese, clay, and common salt was added; the temperature was now raised, and 40 lbs. of pig-iron was placed on beds of cinder near the fire-bridge, which on beginning to melt was raked down into the melted bath below, and thoroughly mixed with it. Grains of steel then begin to appear, when the temperature is reduced while the bath is stirred beneath the layer of cinder, after which the balling is effected as before with the damper closed.

The Siemens furnace has been applied to this process with a considerable saving in fuel. The product, however, is never uniform, and from the intermixture of cinder, etc., requires remelting before it can be applied to many purposes; it also welds imperfectly.

The following analyses of the pig-iron employed, and the steel produced in this process, are by Schilling.*

	Puddled Steel.	Pig-Iron.
Graphite, - - - - - -	...	·08
Combined Carbon, - - - -	·94 per cent.	2·60
Sulphur, - - - - - -	Trace.	·09
Phosphorus, - - - - -	·075 ,, ,,	·48
Silicon, - - - - - -	·11 ,, ,,	·99
Manganese, - - - - -	·27 ,, ,,	2·01

It will be observed from these analyses that the change in composition from pig-iron to puddled steel, is exactly analagous to that which takes place in puddling for malleable iron, viz., a very considerable decrease occurs in the percentage of the whole of the elements—carbon, sulphur, phosphorus, silicon, and manganese—a result which, in regard to sulphur and phosphorus, contrasts strongly with the result when the same pig is treated in the Bessemer process, where these elements remain in the final product undiminished, or even concentrated. For the more perfect elimination of the

* Bauerman, *Metallurgy of Iron.*

deleterious elements, sulphur and phosphorus, during the puddling and other steel-making processes, various *physics* have been proposed for addition to the charge at different stages; of such are "Schafhäutl's powder," consisting of oxide of manganese and common salt, with a little potter's clay; while other mixtures contain carbon, chromate of potash, ferrocyanide of potassium, cyanogen compounds, etc.

In Westphalia,* puddled steel is rolled into pieces of $\frac{1}{2}$ or $\frac{3}{4}$ of an inch square, and sold in Hamburg under the name of *India steel;* the same steel when hardened, is sold as *Mailand steel.*

146. Heaton Process.—In the Heaton or *nitrate* process for the production of steel, the pig-iron is first converted by treatment with nitrate of soda into what he calls "crude steel," which product requires to be broken up and melted in crucibles for the production of cast-steel. The converter employed, fig. 44, consists of a cylindrical wrought-iron cupola, surmounted by a cone, and terminating in a short vertical chimney; the whole is lined with refractory material, as fire-brick or fire-clay. The bottom, which is raised above the level of the floor to allow of the introduction of a waggon or truck beneath it, is made movable and secured to the cupola by iron clamps. In conducting the process, nitrate of soda, forming about 10 per cent. of the charge, sometimes mixed with sand and air-slaked lime, is first placed on the bottom B of the cupola, and prevented from at once floating up through the liquid metal by a closely-fitting cast-iron grate or perforated plate C, which is placed upon it; the molten pig-iron is then introduced through the opening A, when in about two minutes† brown nitrous fumes appear, succeeded by blackish, grey, and then whitish fumes, and in about five or
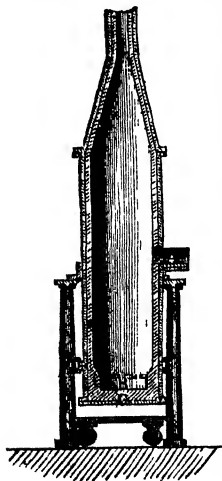
Fig. 44.—HEATON CONVERTER.

* Crookes' and Rohrig's *Metallurgy.*
† Professor W. A. Miller's Report on the process.

six minutes the plate separating the iron from the nitrate of soda is melted, and a violent decomposition ensues accompanied by an active ebullition and the emission of a bright yellow flame from the top of the chimney; this continues for about a minute and a half, when the action ceases, and the metal quietly subsides. The charge is not usually sufficiently fluid to be run out into moulds, so the bottom of the converter is detached and received into a truck beneath, when the product or *crude steel*, along with the slag, is poured on to the iron floor; the metal is then broken into pieces of convenient sizes for piling and reheating, when, after shingling, the blooms are cut up, reheated, and rolled into bars, or, if required for the production of cast-steel, the blooms are hammered into flat cakes which are broken up, sorted, and remelted in crucibles.

Analyses of the pig-iron employed and the crude steel as received from the converter, show that the oxidation from the decomposition of the nitrate has had the effect of removing all but a trace of the silicon, while the carbon is partially removed, and what remains is wholly in the combined state. The following analyses, published by the late Dr. W. A. Miller, F.R.S., and Mr. Snelus, respectively, show that the phosphorus and sulphur are but imperfectly removed.

ANALYSIS OF HEATON PRODUCTS (DR. W. A. MILLER, F.R.S.).

	Pig-iron employed.	Crude Steel.
Carbon......................................	2·830	1·800
Silicon......................................	2·950	0·266
Sulphur......................................	0·113	0·018
Phosphorus.................................	1·455	0·298
Arsenic	0·041	0·039
Manganese.............................. ..	0·318	0·090
Calcium	...	0·319
Sodium	...	0·144
Iron (difference)	92·293	97·026
	100·000	100·000

	Two brands of Pig-iron mixed together		Soft Crude Steel.	Hard Crude Steel.
Graphite - - - - -	2·360 } 2·570		1·098	2·061
Combined Carbon - -	0·446 }			
Silicon - - - - -	2·006	1·959	Trace.	0·014
Sulphur - - - - -	0·034	Trace.	Trace.	Trace.
Phosphorus - - -	0·446	0·558	0·344	0·489
Manganese - - - -	0·648	0·885	0·072	0·064

147. Uchatius' Process.—This process, patented in 1855, depends for its success upon the decarburization of pig-iron by heating it with roasted ores of iron. For this purpose the pig-iron is melted in a cupola, and granulated by running the melted metal into cold water, by projecting it in globules, by allowing the melted metal to fall upon a horizontal revolving disc or dash wheel, or any other method by which the pig-iron can be obtained in small particles. The granulated iron is heated in crucibles along with 20 per cent. of its weight of roasted pulverized oxide of iron or spathic iron ore, a little black oxide of manganese, and about 4 per cent. of fire-clay, this latter serving to form a slag with the extraneous matters of the ore. The spathic ore (carbonate of iron and manganese) is oxidized by roasting to peroxide of iron, etc., which, in the crucible, is reduced by the carbon of the pig-iron with the evolution of carbonic oxide and consequent decarburization of the contents of the crucible. The product of cast-steel exceeds by about 6 per cent. the weight of pig-iron employed.

The finer the granulation of the pig-iron, the softer or milder is the temper of the steel produced; the temper is also regulated by the addition of small pieces of malleable iron or of charcoal to the charge, according as the temper is required to be lowered or the metal hardened. In Sweden this process is carried on successfully by melting pig-iron with certain Bispberg magnetic iron ores. In England, however, the uncertainty in the quality of the cast-steel produced has prevented its extensive introduction.

148. Ellerhausen's Process.—This process is similar to the last, but differs in the manipulation. The pig-iron is run directly from the blast furnace along a spout into moulds formed on the circumference of a revolving table; at the same time, another spout delivers into these moulds finely divided *hæmatite, iron sand* or powdered *magnetite*, the result being, that by revolving the table as each mould is filled, a series of pigs or blooms of pig-iron mixed with about 15 per cent. of iron ore are obtained. These *pig-blooms* are melted and puddled in the puddling furnace; and it is stated that the metal in this condition is more easily puddled than ordinary pigs, giving also an increased yield of metal. The process can be applied either to the production of malleable iron or steel, according to the degree of decarburization effected in the puddling process; but the method is not received with favour in England.

Numerous other patents exist for the fusing of mixtures of pig-iron with special ores of iron, with substances as arsenious acid, nitre, etc.; but the difficulty encountered in the whole of these processes appears to be the uncertainty of the quality and temper of the product.

149. Henderson Process.—This process, known also as the *fluorine process*, has for its object the removal of sulphur, phosphorus, and silicon from pig-iron, by the action of fluorides upon the metal during its conversion into steel or malleable iron. In one modification of the process, a titaniferous pig-iron is first produced by fusing pig-iron as that of the Cleveland district with titaniferous iron ore, and then charging this titaniferous pig upon the bed of a puddling furnace, the bottom of which has been covered with fluor spar (fluoride of calcium). The metal requires no rabbling, except for balling up the finished product.

In the second modification a mixture of 48 lbs. of fluor spar with 118 lbs. of titaniferous iron ore, both ground fine, is spread evenly over the bottom of the puddling furnace, and the charge of 475 lbs. of pig-iron placed thereon. The furnace, thus charged, is closed so as to prevent the access of air, and the temperature is raised as high as possible; after a lapse of seventy minutes samples are taken from the bath every few

minutes to ascertain the progress of the conversion, and in about an hour and a half the operation is completed. The metal should not be stirred or rabbled during the conversion, since the mixture of fluor spar and titaniferous iron ore is only rendered viscous, and not perfectly fluid, by the heat attained in the furnace; and if stirring be not resorted to, it will remain on the bottom of the furnace, where the fluor spar will be decomposed by the reaction upon it of the silicon and other elements of the pig-iron.

150. Parry's Process.—Mr. Parry states that the ordinary puddling process effects the removal of about 75 per cent. of the phosphorus, and from 65 to 70 per cent. of the sulphur present in the original pig-iron; and his improved method of manufacturing malleable iron or steel consists (1°) the reconversion of *wrought-iron scrap* (that is, pig-iron that has been subjected to the puddling operation) into *pig-iron*, without the introduction of a further amount of sulphur or phosphorus; and (2°) repuddling of this product. By these means he effects the removal of 65 or 70 per cent. of the sulphur, and about 75 per cent. of the phosphorus which forms the residue left in wrought-iron or puddled pig, thereby obtaining a product practically free from these noxious elements, to the improvement in the quality of the malleable iron produced; and, if necessary, the conversion into pig-iron and *repuddling* may be repeated a third time, each conversion being attended with a diminution in the amount of the sulphur and phosphorus present in the product. The reconversion into pig-iron is effected in a cupola or blast furnace, the increased temperature necessary for the recarburization being obtained by inclining one or more of the twyers at an angle of 30° or 35° downwards. The charges consist of about 7 cwt. of coke per ton of iron, with sufficient lime to flux the ash of the coke; the furnace must be kept filled during the melting, otherwise an insufficient amount of carbon will be taken up, about 2 per cent. being necessary to produce the boil in the puddling furnace, and to this extent the wrought-iron must be carburized. The metal from the furnace is tapped in the usual manner into pigs, which are puddled in an ordinary furnace and rolled into merchant bars in the usual manner. The product is called *purified wrought-iron.*

For making hard steel, Mr. Parry repeats the carburization just described, except that the amount of coke used is reduced from 7 cwt. to 4 or $4\frac{1}{2}$ cwt. per ton of metal, and the size of the nozzles of the twyers is slightly increased. For the production of soft or mild steel, the metal so obtained is run out into an oval-shaped vessel or receiver of wrought-iron, lined with a mixture of clay and sand, and connected with a blowing apparatus for passing air through the mass; after a few minutes' exposure to the blast, the temper of the metal is sufficiently reduced, and it is run out from the tap-hole in the bottom of the vessel into ingots or other forms.

151. Malleable Cast-iron.—The operation of converting the surface of articles of cast iron into malleable iron or soft steel, is a process analagous to the cementation of steel, except that instead of carbon, the cement powder consists of powdered peroxides of iron, a decarburizing material. The object of the process is to partially remove the carbon, sulphur, silicon, and manganese from the surface of articles made of cast-iron, and so impart to them the strength and softness of malleable iron or mild steel; for this purpose the articles are cast in moulds in the usual manner, the iron preferred for the purpose being charcoal pig smelted from red hæmatites, and the castings so produced are then packed into suitable boxes or crucibles, with powdered red hæmatite. A number of these crucibles are arranged in a rectangular furnace chamber, and the heat gradually raised, when in about twenty-four hours the whole contents of the furnace are at a red heat; the heat is then continued for from three to seven days, according to the size of articles, and the extent or depth to which it is desired that the decarburization shall penetrate.

Malleable cast-iron cannot be welded or worked when heated, since there remains an inner nucleus or kernel of cast-iron, which, melting below the welding heat of steel, causes the object to fall to pieces at the stroke of the hammer; the surfaces may, however, be readily brazed together and, in the cold state, the castings may be hammered to a certain extent, or can be filed or fitted as articles of malleable iron.

PRODUCTION OF STEEL BY THE FUSION OF PIG-IRON WITH
MALLEABLE IRON.

152. Siemens-Martin Process.—In this process, cast-steel is manufactured by the fusion of pig-iron with varying proportions of malleable or bar-iron scrap, crop ends of rails, and other Bessemer steel scrap.

Grey pig-iron, such as is required for the Bessemer process, is employed, the whole charge consisting of from 9 to 10 per cent. of such pig-iron, with about 6 per cent. of speigeleisen, the remainder being made up of scrap-iron and steel. The pig-iron may be melted in a separate furnace before its introduction into the Siemens furnace, or it may be placed at once on the heated bed of the furnace and allowed to melt there. The bar-iron or scrap-steel must be heated to whiteness before mixing with the bath of pig-iron, and for this purpose is either heated in a distinct furnace, or placed on the furnace hearth, so as to become white hot before melting and running down into the bath of pig-iron. The process is conducted in a Siemens furnace specially arranged for the purpose; the bed B, similar in shape to that of a puddling furnace, slopes slightly from all sides towards the tap-hole k, and is supported on cast-iron plates kept cool by a current of air circulating beneath them, the regenerators A and G admitting air and gas respectively to the furnace, being placed transversely beneath the bed; and the coal used in the generators or producers consists of equal parts of binding coal and small coal slack. The furnace has three doors, one n over the tap hole forms the working door of the furnace, and one at each end near to the bridges serves for the introduction of the scrap-iron or steel, which requires to be placed near the bridge so as to be heated by the flame, before passing into the molten bath of metal on the bed of the furnace. For the introduction of long bars and old rails, etc., sloping shoots are made at the back of the furnace, along which, by partially opening them to the air, the flame of the furnace will pass, heating the bars placed in them before they fall down into the bath below. The bottom of the furnace is formed of fine quartzose sand, introduced when the furnace is hot in layers of about 1 inch in thickness, each layer
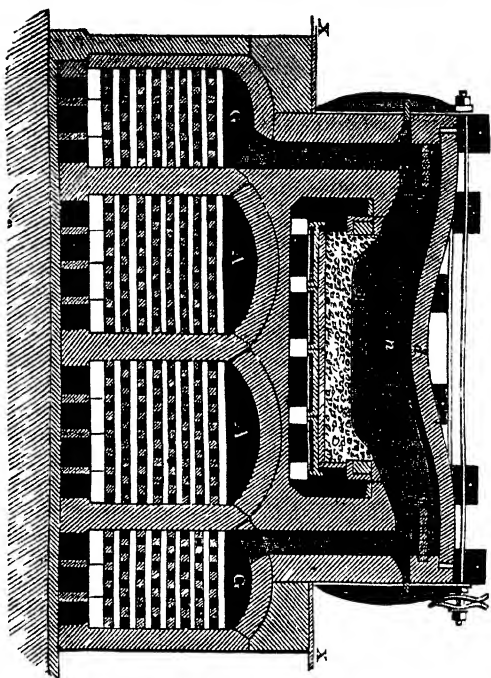
Fig. 45.—*Longitudinal Section.*

SIEMENS' OPEN HEARTH STEEL MELTING FURNACE.
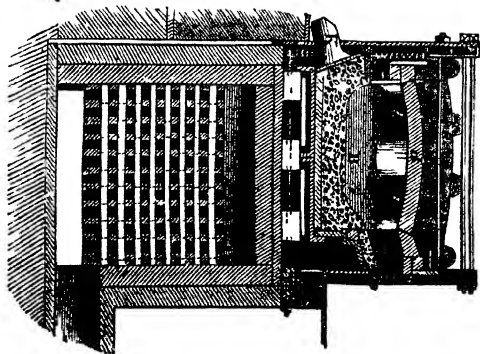
Fig. 46.—*Cross Section.*

being rammed down and allowed to partially vitrify or become glazed on its surface by the heat of the furnace before another is introduced; the roof d of the furnace is built of Dinas brick.   The furnaces are built in sizes to melt from 2 tons to 5 tons of steel at each charge.

For a 3 ton charge, about 6 cwt. of grey pig-iron is introduced into the furnace already heated to whiteness; heavy scrap is placed on the bed of the furnace near the bridges, where it is thus heated to whiteness before introduction into the bath of molten iron, while rails about 6 feet in length, bars of iron, etc., are introduced into the shoot previously mentioned, their lower ends only resting upon the hearth or bed of the furnace; the bars descending as their lower extremities melt away, when other bars are added to replace them until the whole charge has been introduced. After about four hours from the commencement of charging, during which time an oxidizing flame has been maintained, and the gas and air valves reversed after every twenty minutes, the whole charge is melted. Samples of the metal are now taken out in an iron ladle from time to time, and cooled in water; and when this test specimen exhibits on breaking the necessary toughness and malleability, notwithstanding its sudden cooling in water, from 3 to 4 cwts. of speigeleisen, according to the temper required in the steel, is charged through the side doors on to the hearth of the furnace close to the bridge at the flue end of the bed; in about twenty minutes it will have melted and run down into the bath of melted metal; the fluid mass is then well stirred so as thoroughly to mix the charge, which is then tapped as quickly as possible to prevent the loss of manganese in the form of slag.   To tap the metal, the sand near the tap-hole is removed, and the hard crust formed on the surface of the furnace bottom is pierced by a bar, on the withdrawal of which the metal runs out into a ladle, furnished with a plug, similar to those used in the Bessemer process; from which it is run into ingot moulds in the usual manner.   The process from beginning to end occupies about ten hours.

The speigeleisen employed should contain at least from 8 to 9 per cent. of manganese.   An average charge* consists

of 20 per cent. of pig-iron, 20 per cent. Bessemer steel scrap, 10 per cent. rough puddled iron, 15 per cent. Siemens scrap, 15 per cent. old iron and borings, with 20 per cent. iron shearings, after which, about $7\frac{1}{2}$ per cent. of speigeleisen is added.

The loss of metal in this process is from 5 to 8 per cent.; it effects a considerable saving in the items of fuel and labour, as compared with other steel making processes; whilst at the same time utilizing the large quantities of scrap made in the Bessemer process.

153. Bessemer Process.—In this process the conversion of pig-iron into malleable iron or steel is effected wholly by the direct chemical action of atmospheric air upon molten pig-iron, and without the intervention of those reactions between the elements of the pig-iron and the oxides of iron and manganese which take place in the decarburization of pig-iron by the operation of puddling, which reactions appear necessary for the elimination of the elements, sulphur, phosphorus and copper, from the product; for, whereas, in the puddling operation, these elements are removed to the extent of about 75 per cent. of the amount present in the pig-iron, in the Bessemer process they are scarcely if at all affected; the percentage of sulphur in the Bessemer metal being but little reduced, while the amount of phosphorus is slightly in excess of that contained in the original pig-iron employed: not that the total amount of phosphorus has absolutely increased, but it has increased relatively, since a considerable amount of the impurities, as carbon and silicon, as also of manganese, are removed from the pig metal by the process, leaving a proportionately smaller amount of iron for combination with the phosphorus, etc. The carbon and silicon are almost entirely burnt out during the conversion; the manganese also is eliminated from the product, but its presence in the pig-iron, in the first instance, is advantageous for the production of a superior metal, since, so long as any manganese remains unoxidized, only a very small proportion of iron is oxidized by the blast; any excess of oxygen introduced being applied to the conversion of the manganese into protoxide, which then combines with the silica from the silicon of the metal or lining of the converter, with the formation of a readily fusible slag. From these observations

it is obvious that the method can only be applied to the working of those qualities of pig-iron that are practically free from sulphur, phosphorus, and copper; of such are the irons smelted from hæmatites and magnetic ores, the demand for which class of ore has given an impetus to the mining and metallurgical industries of the North of England unprecedented in the annals of any other mining district, the Cumberland hæmatites being in special demand for conversion into steel by the Bessemer process.

In the earlier patents of Mr. Bessemer, he proposes to force air or steam, or air and steam, amongst the particles of molten pig-iron until the metal has acquired the malleability and other qualities of steel; for this purpose he introduced the blast from the top of his converting vessel by a tube or hollow rabble passing towards the bottom of the vessel, whereas, at the present time, the blast is introduced by a number of twyers through the bottom of the converter, the air passing upwards through the mass of molten metal. The use of steam, it is scarcely necessary to remark, is impracticable, since the cooling effect, due to the large absorption of heat occurring from the decomposition of the steam on its passage through the fluid pig-iron, rapidly solidifies the charge, instead of raising the temperature of the metal to the high degree necessary for the Bessemer blow, as occurs when air alone is similarly passed through the molten mass.
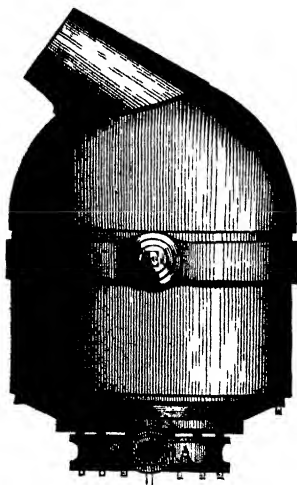
Fig. 47. — SIDE ELEVATION OF THE BESSEMER VESSEL OR CONVERTER.

The Bessemer *converter* or *vessel*, in which the blow is conducted, has the form shown in fig. 47, the neck or mouth inclining over at an angle of

about 30° to the body of the converter, so that the flame and sparks are directed away from the workman and the casting-pit to be subsequently mentioned; also the position of the mouth prevents, to a very considerable degree, the ejection of the molten metal, which would otherwise occur during the violent disturbance attendant upon the blowing of the charge. The size of the mouth is also of importance, for if too large it is attended with a loss of heat, and part of the converted metal is apt to solidify upon, or coat the surface of the vessel; and if too small, an undue back pressure results, and the operation is retarded. The vessels are made of sizes capable of blowing or converting from 3 to 10 tons of metal at each charge, and are called respectively, 3, 4, 5—10 ton converters. A 6-ton converter is about 8 feet in height, and 12 feet 6 inches in diameter outside. The converter is formed of an outer skin or shell of wrought-iron plates, $\frac{5}{8}$, $\frac{3}{4}$, and $\frac{7}{8}$ inch in thickness, riveted together, and lined in the inside with 10 or 12 inches in thickness of a most refractory material, usually "ganister," or a layer of fire-brick may be first built in the outer shell, and this covered to a depth of a few inches with ganister. In order to line the converter, the ganister is ground to a tolerably fine powder, and either used alone or mixed with a small quantity of powdered fire-brick; the twyer box A, and the plates forming the bottom of the converter are removed, when the mouth of the vessel is closed by a piece of wood, and then turning the converter mouth downwards, a wooden core of the internal size of the converter is introduced, and the moistened ganister rammed well in between the shell of the converter and this core, which is then withdrawn. The bottom of the converter is connected with the body of the vessel by bolts and cotters, its inner surface being made flat, as shown, and it is penetrated by from seven to twelve (according to the size of converter) conical clay twyers a, a, fig. 48, which in a 6-ton converter are 20 inches in length, and each containing twelve holes or apertures for the admission of the blast to the converter. The twyers are introduced from the lower side or twyer box, and carefully luted around to prevent the escape of metal into the space A. The bottom plate of the box A is readily removable for

obtaining access to the twyers, each of which is held up in its position by a stop or horizontal arm *b*, capable of rotation to one side when it is necessary to withdraw and replace any one of the twyer bricks. The twyer box or air chamber is connected by a curved pipe *e*, elliptical in section, with the hollow trunnion E of the converter, and so with the blowing apparatus. A stout belt, hoop, or trunnion of wrought-iron, is placed around the body of the converter, the arms
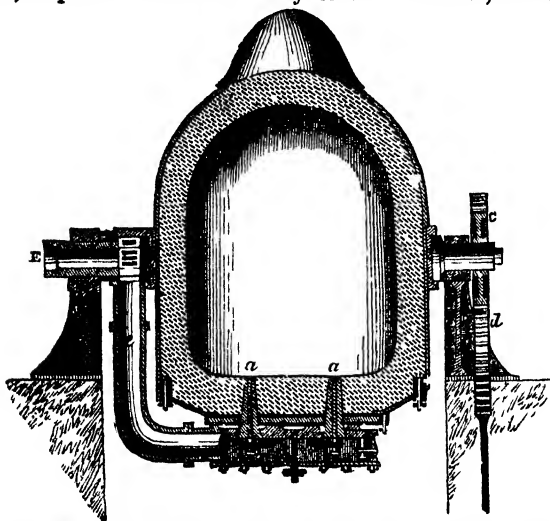
Fig. 48.—VERTICAL SECTION THROUGH THE TRUNNIONS OF THE BESSEMER CONVERTER.

of which rest upon bearings in the cast-iron standards D; one arm E of this trunnion is hollow, and connected by suitable valves with the blowing cylinders; the other arm is solid, on to which is keyed a spur pinion *c* gearing, with a vertical rack *d* actuated by a hydraulic piston or ram placed below, and which is under the control of the workman (vesselman)—the converter being capable of rotation in a vertical plane through an angle of 180°. Formerly, it was the practice to make the blast automatic, so that when

the blow was over, and the vesselman turned down the converter for discharging its contents, the trunnion in its revolution closed the valve connected with the blast; this mechanism is, however, liable to derangement, and the blast is now generally shut off by an independent valve. When the converter is vertical, its mouth is directed towards an open rectangular space, or to a hood forming the bottom of a kind of stack, which takes away the gases and sparks thrown out from the converter during the blow.

It is usual in Bessemer steel works to place the converters in pairs, either on the same or opposite sides of a casting-pit, a small cupola or wind furnace being situated between the two for melting the charge of *speigel* to be added at the end of the blow; the cupola being raised sufficiently high to allow the speigel to be tapped directly from the furnace into an iron trough lined with sand leading to either convert r, or so that it may be first tapped into a ladle and weighed before emptying into the converter. The casting-pit is occupied by the ingot moulds for the receipt of the metal and the apparatus for discharging the metal into these moulds. In the centre is a hydraulic lift or casting crane formed by a hydraulic piston or ram, to the top of which is attached a platform formed by a pair of wrought-iron girders well braced together; this platform receives at one end the ladle into which the metal is emptied from the converter, at the opposite end to which is a mass of iron, acting as a counterpoise to the weight of the ladle and its contents; a handle connected with the necessary gearing enables a man standing at the middle of this platform to traverse the ladle inwards or outwards, so as to bring it exactly over the centre of the ingot moulds; and by another handle or wheel he is able to rotate the crane around the pit, thereby emptying its contents into moulds placed in any part of the pit, while a third movement enables him to raise the table so as to come over moulds of varying height.
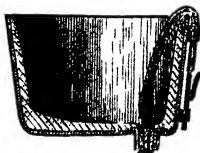
Fig. 49.—BESSEMER CASTING LADLE.

The ladle (fig. 49) resembles the ordinary ironfounder's casting ladle; it is formed of iron plates riveted together, and lined

on the inside with refractory material, as sand or ganister; but, instead of pouring the metal from a lip, it is tapped from the bottom, for which purpose the bottom inclines from all parts to one side where the tap-hole is situate; a fire-clay nozzle attached to a vertical iron rod, also coated with fire-clay, fits into this hole, and by connecting the top of this rod with a hand lever, the nozzle can be raised or lowered so as to allow sufficient metal to escape to fill any required mould, when by depressing the lever, the nozzle or plug is reinserted and the stream is stopped until the ladle is placed over another mould. The moulds employed for casting ingots of Bessemer steel are of cast-iron, open at both ends, and octagonal or circular in section, with a considerable taper from top to bottom so as to allow of the ready extraction of the ingot therefrom.

The charge of the Bessemer converter consists, as already noted, of from 2 to 10 tons of molten pig-iron, the most usual charges, however, varying from 3 to 6 tons. Previous to the introduction of the molten metal into the converter (unless the vessel is already hot from a previous charge), a fire is made up in it, a quantity of coke thrown in, and the blast turned gently on; this is continued until the inside of the converter is at a red heat, when it is turned upon its axis, so as to bring the mouth downwards, and the coke, etc., is emptied into the pit beneath the converter, the blast being blown through to drive out the coke; the converter is now rotated into a horizontal position, when the charge of pig-iron, which has been melted in a reverberatory or cupola furnace placed in the vicinity of the converter, is run along a movable gutter of wrought-iron, lined with sand or ganister, into the red-hot vessel; or, as is practised in Sweden and the continent, the metal may be tapped directly from the blast furnace into the converter. Before running in the pig-iron it is not unusual to throw into the converter 10 per cent., or even 20 per cent., of the charge in the form of scrap-steel, such as rail ends, skulls, etc., either cold or heated to whiteness in a neighbouring furnace; in the case of light scrap it is melted down in the cupola along with the pig-iron. Owing to the shape of the converter, when in a horizontal position, the twyers are above the bath of metal thus introduced; the

blast is now turned on, and the converter rotated into a vertical position, the passage from the horizontal to the vertical being accompanied by the ejection of a shower of sparks and graphite blown out by the blast; on assuming the vertical position, however, during the first three or four minutes, only a small very slightly luminous flame, accompanied by sparks, is visible from the mouth of the converter; after which the flame becomes a little more luminous and unsteady, and in from eight to ten minutes the flame is very dense, yellow, bright, and considerably increased in size. The metal is now in a violent state of ebullition, showers of slag, sparks, and burning iron are frequently ejected from the mouth of the converter, while the pressure of the blast, which at first was from 15 lbs. to 20 lbs. per square inch, falls to 10 or 11 lbs.; this stage, or what is known as the *boil*, continues for from six to eight minutes, with a charge of 3 tons of metal, and towards the conclusion of this stage the flame becomes less dense, and assumes a characteristic rose or pale amethyst tint, indicating the last or *fining* stage of the blow, during which the flame is diminishing in size and intensity, and in from eighteen to twenty minutes from the commencement of the blow the flame finally *drops*, an indication that the blow is at an end ; the converter is then quickly turned down into the horizontal position, the blast turned off, and from 7 per cent. to 10 per cent. of melted speigeleisen or other highly carburetted and manganiferous alloy is added to the contents of the converter, the immediate effect of which is the emission from the mouth of the converter of a long, roaring, and extremely luminous jet of flame, the appearance of which is a further indication that the blow was completed before the converter was turned over. Formerly, it was the practice to place the converter vertical, and continue the blowing for a short time after the addition of the speigeleisen, but for some time this practice has been discontinued. The metal, which is as fluid as water, after standing for a few seconds is transferred, along with a quantity of slag, from the converter to the casting ladle, previously heated by burning charcoal or coke within it ; the slag floats on the top, and assists in retaining the heat of the fluid metal during the casting operation. The converter is now turned

mouth downwards, when the slag that had remained behind drains out into the pit below.   As each ingot mould is filled with metal its surface is covered with sand, and a cast-iron plate, secured by wedges and eye-bolts to the ingot mould, is placed on the top to prevent, as far as possible, the rising of the metal on solidification, and thereby rendering the top of the ingot unsound and honeycombed.

The duration of the blow just given applies to a 3-ton blow consisting of English hæmatite pig-iron, or this mixed with only a small proportion of Swedish irons.   If Swedish pig-iron be used alone, the blow is much shorter; instead of lasting from sixteen to twenty minutes, it will be over in from thirteen to fifteen minutes for a 3-ton charge; the process altogether requiring greater care that the blowing be not continued beyond the point of total decarburization by even a few seconds, otherwise considerable practical difficulties arise from the deposition of a film or coating of metal on the inside of the converter, requiring much labour to detach it. For heavier charges of metal the time of blowing is proportionately increased, a blow of 8 tons of hæmatite pig-iron requiring from forty to fifty minutes for its completion.

The Bessemer process, as above described, consists in continuing the blow until the charge is totally decarburized, and then restoring the necessary amount of carbon to convert the whole into steel, by the addition of an amount of speigeleisen proportional to the temper required in the product. In Sweden, however, the process was formerly conducted by stopping the blow before complete decarburization had been attained, leaving thereby an amount of carbon in the metal equal to the production of the desired temper; but the difficulty of being able to stop the process at the exact period, led to the almost general introduction of the total decarburization method as practised in England.   In Styria, again, the iron employed contains from 1 to 3 per cent. of manganese, and, instead of adding speigeleisen to the converted charge, the necessary amount of carbon is introduced by the use of a quantity of pig-iron of the same kind as the original charge.

It is usual in England to stop the blow, that is, turn over the converter at the instant the flame falls; in Austria and

Sweden* the progress of the operation is judged from the character of the slag; an iron rod is inserted into the converter, and, when brought out, a portion of slag adheres to the point; so long as any carbon remains unconsumed, a peculiar brownish tint is observed, but as soon as the point of total decarburization is reached, the slag assumes a dead black colour, with a peculiar metallic lustre, due to the presence of oxide of iron.

If the blowing be continued after the oxidation of the whole of the carbon is completed, the heat is maintained by the combustion of the iron itself, and the product is deteriorated in quality, approaching in character towards burnt iron, in proportion to the extent of overblowing; at the same time it is attended with considerable loss in the yield. If much overblown, the converter, as also the sides and bottom of the ladle, are coated with a thick crust of metal; this crust, solidified, of the internal form of the ladle, is technically called a *skull*, and when produced is usually broken up and introduced with the next charge as scrap-steel. Overblowing of the metal for only a few seconds is sufficient to create a skull in the ladle of considerable weight.

About four charges are worked off in a day from each converter; for although the actual blowing lasts only about twenty minutes, the melting of the pig-iron and removal of the ingots from the pit, with the rearrangement of the moulds, occupy a considerable time. After five or six blows the converter requires new twyers, the brick being eaten down to a considerable depth below the level of the bottom. For their insertion, the bottom plate of the twyer box is removed, the old twyers knocked out and new ones inserted from the bottom, luted around, and secured as previously described; the converter is then turned up, and a quantity of a thin paste of ganister and fire-clay is run in around the twyers in the inside of the bottom. After about eighty blows the converter usually requires relining, frequent repairs of the lining having been effected in the meantime by ramming patches of ganister on the more corroded and broken down parts of the lining.

The total yield of Bessemer metal produced averages from

* Bauerman.

80 to 85 per cent. of the total weight of pig-iron and speigeleisen introduced into the cupola or other remelting furnace.

The decarburized metal obtained at the termination of the blow, and before the addition of speigeleisen, behaves on mechanical treatment exactly as burnt iron; it is found to be exceedingly *red-short*, that is, cannot be welded or hammered at a red heat, but crumbles and falls to powder on attempting to work it under the hammer; this rottenness or want of cohesion in the product is generally allowed to be due to the presence of a surplus of oxygen and silicon in the intensely heated metal, which elements are removed by the addition of *speigeleisen* or other alloy rich in manganese, owing to the very powerful affinities of oxygen, silicon, and manganese for each other, whereby the three pass out as a fusible slag, and the metal has restored to it all the qualities of good steel, the hardness of temper depending on the amount of carbon introduced in the manganiferous alloy.

154. Decomposition in the Bessemer Vessel or Converter.—The following analyses* of the pig-iron employed, steel produced, and of the metal at various stages of the process, as determined at the Austrian works of Neuberg, and by Mr. Snelus at the Dowlais works, show that during the first stage of the process the operation is attended with the conversion of the *graphite* into *combined carbon*, and a very considerable diminution in the amount of silicon, indicating that the *silicon* is burnt off in the earlier stages of the blow much *more rapidly* than the *carbon*, while in the last stage the reverse is the case; at the same time the analysis of the slag produced at this period, No. II., shows that the manganese is being rapidly oxidized, the oxide so formed combining with silica, with the formation of a fusible silicate or slag; while in the same period the iron is comparatively unaffected. During the boil the carbon, silicon, and manganese, as indicated by the analysis No. III., are suffering combustion, whilst at the conclusion of the last or fining period, there is present in the metal but a few hundredths per cent. of these

* *Journal of the Iron and Steel Institute.* Paper by Dr. Roscoe. 1871

ANALYSES OF THE METAL TAKEN FROM THE CONVERTER AT
DIFFERENT STAGES OF THE BLOW AT THE NEUBERG WORKS.

	I.	II.	III.	IV.	V.
Graphite, ...	3·180	...	...	...	...
Combined carbon,	0·750	2·465	0·949	0·087	0·234
Silicon, ...	1·960	0·443	0·112	0·028	0·033
Sulphur, ...	0·018	Trace	Trace	Trace	Trace
Phosphorus, ...	0·040	0·040.	0·045	0·045	0·044
Manganese, ...:...	3·460	1·645	0·429	0·113	0·139
Copper,..............	0·085	0·091	0·093	0·120	0·105

ANALYSES AT THE DOWLAIS WORKS.

	I.	II.	III.	IV.	V.
Graphite, ...	2·07	...	...	...	..
Combined carbon,	1·20	2·127	1·55	0·097	0·566
Silicon, ...	1·952	0 795	0·65ͻ	0·020	0·030
Sulphur, ...	0·014	Trace	. .	Trace	...
Phosphorus, ...	0·048	0·051	0·064	0·067	0·055
Manganese, ...	0·086	Trace	...	Trace	0·309
Copper,..............	...	...	.ͳ.	...	0·039

ANALYSES OF SLAGS PRODUCED AT DOWLAIS.

	II.	III.	IV.	V.
Silica,..........................	46·78	51·75	46 75	47·27
Alumina, ...	4 65	2·98	2·80	3·45
Iron protoxide, ...	6 78	5·58	16·86	15·43
Manganese protoxide,..	37·00	37·90	32·23	31·89
Lime, ...	2·98	1·76	1·19	1 23
Magnesia, ...	1·53	0·45	0·52	0·61
Alkalies,.......................ͻ.....	Traces	Traces	Traces	Traces
Sulphur, ...	0·04	Traces	Trace	...
Phosphorus, ...	0·03	0·02	0 01	0·01

I. Original pig-iron.
II. Metal and slag taken at the end of the first period (6 minutes).
III.   ,,   ,,   boil   (12 minutes).
IV.   ,,   ,,   blow
V. After addition of speigel.

elements (No. IV.), and the corresponding analysis of the slag indicates a sudden increase in the amount of iron, showing that at the end of the boil the manganese is practically removed, and that during the fining or last stage of the process, the iron begins to suffer oxidation and waste.   No. V. is the analysis of the Bessemer steel produced after recarburization by the addition of the speigeleisen, in which it is also noticeable that the percentage of phosphorus and sulphur differs but slightly from the amounts shown in the analysis of the original pig-iron.

Mr. Snelus, in a paper to the Iron and Steel Institute, communicates the following as the composition of the gases escaping from the mouth of the converter, during a blow lasting eighteen minutes:—

	I.	II.	III.	IV.	V.	VI.
Carbonic acid,	10·71	8·59	8·20	3·58	2·30	1·34
Carbonic oxide,	None	3·95	4·52	19·59	29·30	31·11
Oxygen, ...	0·92	...	...	...	...	...
Hydrogen,...		0·88	2·00	2·00	2·16	2·00
Nitrogen, ...	88·37	86·58	85·28	74·83	66·24	65·55
	100·00	100·00	100·00	100·00	100·00	100·00

    I. Taken 2 minutes after the commencement of blow.
     II.   ,,   4   ,,   ,,   ,,
    III. ,,   6   ,,   ,,   ,,
    IV. ,, 10   ,,   ,,   ,,
     V.   ,, 12   ,,   ,,   ,,
    VI. ,, 14   ,,   ,,   ,,

These analyses show that during the first period of the blow, in which the temperature is low, and a very small slightly luminous flame is visible at the mouth of the converter, the carbon is oxidized to carbonic acid; but as the process advances, the temperature is rising, and the proportion of carbonic oxide rapidly increases. Analysis IV., taken ten minutes from the commencement or after the boil has commenced, shows a very large increase in the amount of carbonic oxide gas, attended with a corresponding decrease in the carbonic acid.   At this period the flame has considerably increased in size, and presents the reddish-violet

tinge of the burning carbonic oxide. The proportion of carbonic oxide continues to increase to the end of the blow; and from the experiments of J. S. Bell, Esq., it appears that at very high temperatures, carbonic oxide is more stable than carbonic acid when in contact with metallic iron, which may account for the presence of carbonic acid in the earlier and cooler stages of the process, whilst, as the temperature increases, its place is taken by carbonic oxide.

Mr. Snelus has computed that the heating power of the gases (chiefly carbonic oxide) escaping from the converter towards the end of the blow is, in works blowing 1000 tons of pig-iron per week, equal to the effect produced by a consumption of 25 tons of coke per week.

Dr. W. M. Watts has attempted to determine the temperature of the flame of the Bessemer converter, and he finds that at the commencement of the blow, a wire of gold held in the flame does not melt, whilst towards the middle and end of the blow, the gold was always melted; hence he concludes that the temperature of the flame at the commencement is below 1300° C. (the melting point of gold). An alloy of platinum and iridium, or platinum alone, does not melt at any period of the process; hence, taking the melting point of platinum at 2000° C., it follows that the temperature of the flame, although increasing beyond 1300° C., never attains to 2000° C.

155. Manganese Alloys.—The necessity of an alloy rich in manganese for the success of the Bessemer process, has given rise to the preparation of many special triple alloys of carbon, iron, and manganese, which should be richer in manganese than the ordinary speigeleisen. Such an alloy is that prepared by Mr. Prieger of Bonn, known as Prieger's *ferromanganese*, which occasionally contains 60 per cent. of manganese; this alloy is obtained by treating in graphite crucibles mixtures of peroxide of manganese (pyrolusite), charcoal in large proportion, and granulated cast-iron or scrap-iron in small pieces, the surface of the charge being covered with powdered bottle glass; the reduction is only effected at very high temperatures, and the cost of the alloy becomes excessive. Mr. Henderson, of Glasgow, prepares a ferro-manganese by reducing a mixture of carbonate of manganese and oxide

of iron, both in the state of powder, with an excess of charcoal on the specially prepared coke bed of a Siemens furnace, a reducing flame being maintained during the reduction; for the first few hours a red heat is maintained, with the production of a metallic sponge, which is then run down by raising the temperature to whiteness, with the production of a fusible alloy of carbon, iron, and manganese, containing from 20 to 30 per cent. of manganese.

156. Bessemer Pig-Iron.—The essentials in a pig-iron applicable to the Bessemer process are:—1° almost absolute freedom from sulphur, phosphorus, and copper, since these elements are not sensibly diminished in amount by the Bessemer process; 2° the presence of a minimum of about 2 per cent. of silicon in pig-irons containing only very small amounts of manganese; for though in this proportion it is almost entirely removed during the process, yet its high calorific power—about 7000—renders it valuable as a heat producer, and thus aids in preventing the loss by the production of *skulls*, which takes place when this element is present in insufficient amount; if present in too large proportion, however, the whole of the carbon may be oxidized and eliminated, while sufficient silicon still remains in the metal to deteriorate its quality, about one-tenth per cent. of silicon being sufficient to make Bessemer steel hard and brittle when cold; the presence of an excess of silicon in the pig-iron is also attended with an increased waste of iron in the form of slag; 3° the pig should be of No. 1 or No. 2 in greyness, for the use of white iron is attended with difficulty and loss; its carbon being in the combined state is converted into carbonic oxide in the earlier stages of the process, before the necessary heat of the metal has been attained, and the combustion of the silicon effected; and 4° the presence of manganese in the pig-iron is advantageous, for although entirely removed, so long as any remains in the molten bath of metal, it prevents the oxidation and waste of iron; and acting as a heat producer, is especially desirable therefore in pig-irons low in silicon. Jordan sets down the minimum of manganese at 1 per cent., but this is considerably in excess of what is used in England, where the pig-irons employed are usually highly siliceous. Mixtures

of pig-irons are generally preferred for the Bessemer process, rather than the use of a single class of iron.

157. **Application of the Spectroscope.**—The spectroscope has been applied somewhat extensively on the continent, and to a lesser extent in England, for the analysis of the Bessemer flame, and the determination of the point of total decarburization or point at which the blast should be turned off. It is especially useful where different irons are being continually blown, with the behaviour of which the workman is not familiar. The phenomena, as observed by the naked eye, and through the spectroscope, in a blow of $4\frac{1}{2}$ tons of metal, chiefly hæmatite pig-iron, are tabulated below.

Time from Commencement.	Appearance to the Naked Eye.	Appearance of the Spectrum.
4 minutes.	Very small flame, with sparks of metal.	Faint continuous spectrum.
5 ,,	Pale flame, increasing in size.	Continuous spectrum, with two yellow sodium lines D, flashing across the spectrum.
6 ,,	Flame large, but very unsteady.	Sodium lines have become steady, and fixed.
8 ,	Flame much brighter and larger.	Yellow sodium lines, with lines in the red and violet ends of the spectrum appear.
10 ,,	Flame is very bright and dense; the boil has commenced.	The last spectrum remains with additional lines in the red, also carbon lines in green and blue, with green * manganese oxide lines
15 ,,	Flame is larger, but more transparent.	Lines in the spectrum more distinct, and better defined.
20 ,,	Flame diminishing in size, and not so luminous.	Spectrum fading.
24 ,,	Flame drops, and blow is over.	The green lines of carbon and manganese disappear.

* Dr. W. M. Watts.

In blowing Swedish pig-irons, which are low in silicon, and contain from 1 to 3 per cent. of manganese, the boil commences sooner than when hæmatites are the subject of operation, and the spectrum appears earlier, the yellow line flashing in about thirty seconds, and has become steady or fixed, in from one to one and a half minutes from the commencement of the blow; after which, at about the same intervals as in last case, the other appearances occur, the blow being completed for this charge in about twenty one minutes. The spectrum is not, however, usually so clear, due to the cloud or haze of brown vapour or smoke which ascends from the mouth of the converter when manganiferous pig-irons are under treatment; the spectrum at the same time is generally less complicated, a number of lines in the green and blue portion of the spectrum of the hæmatites being absent.

158. Whitworth Process.—Bessemer or other steel ingots, especially of the softer tempers, when cast in moulds in the ordinary manner, are always open and spongy along the centre line, and present a more or less honeycombed character, especially towards the top of the ingot (fig. 50); if, however, the ingot be cast under the pressure of a very considerable head of metal, the lower portion may be sound, but the upper portion is still honeycombed. Sir Joseph Whitworth,

has succeeded in overcoming this difficulty of unsoundness in steel ingots, by submitting the metal, while in its fluid condition, to very considerable pressure; for this purpose the steel from the converter or crucibles is run from the ladle into a steel mould lined with refractory material, and constructed so as to allow of the free escape of gas from the metal whilst being pressed; the metal is subjected to a pressure of several tons upon the square inch, by means of large hydraulic presses, specially constructed; such a press at the works of Sir J. Whitworth & Co., Manchester, being capable of exerting a total pressure of 8000 tons upon the fluid metal.

Fig. 50. — CROSS SECTION OF THE UPPER END OF A BESSEMER INGOT.

CHAPTER X.

TIN.

This metal is of high antiquity, the Phœnicians, before the Christian era, having fetched the metal from the British Isles.

Tin is one of the whitest metals, possessed, however, of a peculiar faint yellowish tinge; it rivals silver in lustre, and when warmed emits a faint odour. A bar of the metal when bent produces a peculiar crackling sound, known as the *cry of tin*, supposed to be due to its crystals grinding over each other during the bending movement. Tin is one of the least tenacious of the metals, only lead and zinc being inferior to it in this respect, a wire 2 m.m. in diameter breaking under a load of 24 kilogrammes. It is very malleable; by hammering and heating, *tin-foil* can be obtained of not more than $\frac{1}{1000}$ of an inch in thickness; such *foil*, amalgamated with mercury, forms the silvering on the back of glass mirrors. Tin is easily obtained in crystals, behaving in this respect much like lead and bismuth. The appearance known as *moirée métallique* is formed by treating the surface of metallic tin with a mixture of ten parts of diluted sulphuric acid, with one part of diluted nitric acid, when the surface of the metal becomes covered with a mass of crystalline forms, giving this well-known ornamental appearance. The specific gravity of tin is 7·251, its linear dilatation from 0°C. to 100°C., is $\frac{1}{462}$ of its length. It melts at 230°C., and may be exposed to a strong heat in a *brasqued* crucible, without loss of weight. If heated in the air, it rapidly oxidizes to *stannic oxide* (SnO_2); melted at a low temperature, and poured out, it retains, if pure, its resplendent lustre for a considerable time, the brilliancy of the surface being one test of its purity; for, if impure, the sur-

face will be more or less frosted, áccording to the amount of impurity present. It undergoes little change in dry or moist air (free from sulphuretted hydrogen) at ordinary temperatures, and is hence used for coating iron which is required to resist the action of moisture, the iron affording strength to the plate, while the coating of tin on its surface prevents the rusting away of the iron. Tin has a conductivity for heat less than half that possessed by silver; its surface takes a fine polish, when the radiation from it is also small; hence its value as a material for the manufacture of teapots, and other culinary utensils. It decomposes water at a red heat, is easily soluble in hot hydrochloric acid, with the evolution of hydrogen; boiling sulphuric acid acts violently on the metal, evolving sulphurous anhydride (SO_2), while the dilute acid acting in the cold, liberates hydrogen. Tin is soluble in the fixed alkalies, and diluted nitric acid acts violently upon it, liberating nitrous fumes, and converting the tin into metastannic acid. The chemical symbol of tin is Sn, and its atomic weight 118.

Tin reduces copper, lead, bismuth, and antimony when heated with their oxides. Commercial tin often contains minute quantities of lead, iron, copper, arsenic, antimony, bismuth, and tungsten; and less frequently manganese, zinc, and molybdenum.

The only compounds of tin with the non-metallic elements which are of metallurgical interest, are its combinations with sulphur and oxygen.

159. Stannous Sulphide.—Tin and sulphur combine readily on the application of heat; the resulting mass of stannous sulphide (SnS) generally contains, however, metallic tin. The product is not so fusible as tin, and is somewhat difficult to pulverise. Sulphide of tin, when roasted with access of air, is resolved into sulphurous anhydride (SO_2) and stannic oxide (SnO_2). The sulphides of tin, when heated with iron, suffer decomposition, the result being a compound of sulphur, iron, and tin.

160. Stannic Sulphide.—Stannic sulphide (SnS_2), or *mosaic gold*, is a scaly, micaceous, unctuous mass, somewhat resembling gold in appearance; a strong heat decomposes it into stannous sulphide (SnS) and free sulphur. This com-

pound cannot be formed by the direct union of tin and sulphur, but is prepared by making an amalgam of two parts of tin with one part of mercury, triturating this amalgam with one part of sal-ammoniac (NH_4Cl) and one and a quarter of sulphur, then subjecting the mixture to a gentle heat (not too strongly), when the stannic sulphide remains at the bottom and around the sides of the vessel, in the form of gold-coloured spangles, and hence the name.

161. Putty Powder.—This substance is a crude peroxide of tin (SnO_2), used for giving an opaque whiteness to enamels, and for grinding glass, etc. It is prepared by heating metallic tin on the bed of a reverberatory furnace, and raking off the crude oxide or dross as it is formed; this dross is then subject to calcination, when it becomes whitish in appearance, and after grinding to powder constitutes what is known as " putty powder."

162. Ores of Tin.—*Tin-stone, cassiterite* or *stream-tin* (SnO_2) may be said to be the only ore of tin; it is black or brown in colour; the variety occurring in granite is usually more translucent, paler in colour, and much purer than that occurring in other rocks, the grey ores often containing a considerable amount of silica. Its specific gravity ranges from 6·3 to 7·1. As occurring in Cornwall, it is more or less mixed with a *gangue* of fluor-spar, wolfram, porphyry, granite, galena, blende, copper and arsenical pyrites, mispickel, chlorite, etc., and, in fact, specimens of nearly four-fifths of all the known minerals are found as associates of tin ores under different circumstances; tin ores require, accordingly, a series of careful and somewhat complicated *dressings*, including *stamping, picking,* and *washing* before being ready for the metallurgical treatment proper. When this mineral presents, on breaking, the appearance of a number of concentric layers, it is called *wood-tin*. Tin-stone occurs as grains or rounded detached masses in the old alluvial soils of Brittany, Saxony, Bohemia, East Indies, etc., in which form it is known as *stream-tin*. A mass of rock, containing only from ⅓ to 1 per cent. of tin-stone, may be profitably worked. Cornwall and Devon afford the largest deposits of tin-stone, but tin ores also occur in Malacca, the island of Banca, in Bolivia, and in smaller quantities in the Isle of Man, France, Spain, Russia, etc.

Tin pyrites, bell-metal ore or *sulphuret of tin*, is brass yellow in colour, with a metallic lustre, and contains varying amounts of tin, copper, iron, zinc, and sulphur. No use is made of this ore for the extraction of tin.

163. Roasting.—The ores of tin containing sulphur, iron, and arsenic are first roasted in large calciners, the mass being rabbled at intervals of from twenty to thirty minutes; the temperature, especially at the commencement, being kept down so as not to agglutinate the sulphide of tin, otherwise the decomposition and oxidation ceases, and the mass requires regrinding. The calcination completed, the mass is drawn from the calciner, exposed to the atmosphere for a few days, and then transferred to a large tank containing water ; the heavier portions containing the larger quantity of metal are collected at the bottom of the tank, and are sold to the smelter as *black tin.*

The result of the calcination or roasting has been to volatilize the arsenic as arsenious acid (As_2O_3), and to expel the sulphur largely as sulphurous anhydride, while the mass still retains cupric sulphate with ferric, stannic, and other oxides, of which the first mentioned is dissolved out in the lixiviation, while the ferric oxide, etc., is separated from the heavier stannic oxide by washing.

164. Reduction.—This operation involves two stages—

1° *Smelting*, in which an impure tin is obtained, containing as impurities chiefly iron and arsenic.

2° *Refining* of this impure tin.

The tin ores having been carefully sorted into three qualities, according to purity, the 1° quality being the purest and richest in tin, are smelted separately for tin of the first quality; the 2° contains tin and other metals, and the 3° contains copper, while a 4° consists almost wholly of *gangue*, and is considered useless.

The smelting of tin ore affords an example of a case of the simple reduction of an oxide by carbon, with the conversion of the *veinstuff* or *gangue* into a fusible slag. A high temperature is required to effect the decomposition.

The smelting of *black tin* is now usually performed in reverberatory furnaces, of which the roof is kept as low as possible, with a view to the economy of fuel. The furnace

shown, fig. 52, has a fireplace A about 2 feet long, with
the stack B at the opposite end of the bed; the fire-bridge E,
about 14 inches in depth, is hollow, and without the usual
cast-iron bridge plate, the fire being kept up above the bridge
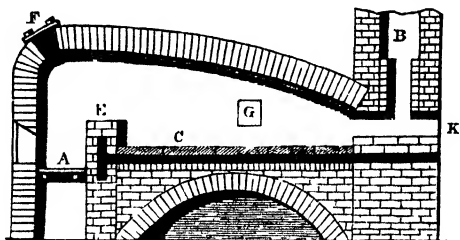
Fig. 51.—Vertical Section of the Reverberatory Furnace
for Smelting Tin.
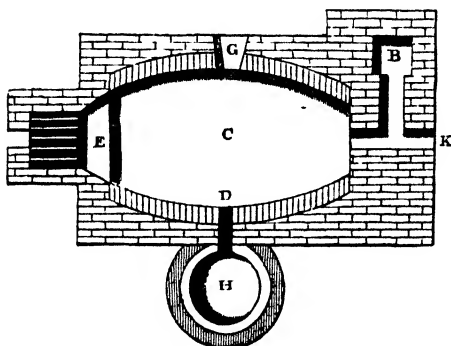
Fig. 52.—Plan of the Bed of the Reverberatory Furnace
and Refining Kettle.

during the smelting operation; the bed C, about 18 feet
in length and 9 feet across, is made shallow, and inclines
from all parts towards the tap-hole D, at the opposite
side to which are the doors G, through which the charge
is rabbled. Below the tap-hole is the *float* H, a quad-
rangular or circular basin of sheet-iron lined with clay,

into which the metal is tapped from the furnace; on the right side of the *float* is placed a *kettle* of cast-iron, set in its own fireplace, in which the operation of refining is performed. The bottom of the furnace is formed of iron bars laid transversely, on which rests a bed of slate, above which is a bed of from 7 inches to 8 inches in thickness of fire-clay, and resting on this are fire-bricks built on end; a bottom thus prepared lasting about three months. Above the *refining kettle* or basin is placed a pulley, from which is suspended an apparatus by which billets of wood may be plunged to the bottom of the pot, and at the same time receive a rotary motion.

The charge of 24 cwt. of ore, yielding a produce of about 65 per cent. of metal, is mixed with one-fifth of its weight of anthracite, and spread over the bed of the furnace; sometimes a little slaked lime or fluor-spar is also added to assist in the fusion of the gangue; the side doors are then luted up and the tap-hole is stopped with clay. The heat is now gradually raised; for if raised too rapidly a loss occurs from the formation of silicate of tin, which escapes reduction. In about five hours after charging the mass is well rabbled, when a quantity of *culm* (anthracite) is thrown into the furnace; the mass is again rabbled after a lapse of about forty-five minutes, and the metal is ready for tapping after a further interval of fifteen minutes. After tapping, a scoriaceous mass remains on the furnace bottom, containing shots of metal and particles of anthracite; this is raked out through the end door K, and forms what the smelter calls *slag*, though the true fused slag, called by him *glass*, runs out of the furnace with the metal on tapping. The glass is essentially a silicate of iron, and when solidified is removed from the top of the metal in the pot or float, and put aside; the skum on the surface of the metal is also skimmed off. For working off this charge of ore about 15 cwt. of coal is required as fuel, and 5 cwt. of anthracite for the reduction of the metal. The slags produced in this smelting, and which are again smelted for tin when the furnaces are not busy, are essentially silicates of iron and alumina, with small proportions of the oxides of tungsten, magnesium, calcium, and manganese, but always containing a considerable proportion of tin; in some cases, as in the

following specimen, as much as 21 per cent. of tin occurring in the slag.

GLASS OBTAINED IN SMELTING TIN.

Silica, ...	36·77
Blue oxide of tungsten, ...	4·93
Stannous oxide, ...	23·87
Ferrous oxide, ...	19·30
Manganous oxide, ...	0·47
Alumina, ...	11·71
Lime, ...	1·83
Magnesia, ...	0·66
	99·54

165. Refining.—The whole of the tin for commerce is subject to the refining operation, although we see quoted *common, refined* and *grain tin,* the difference being that the refined tin is made from the best ores and boiled longer in the refining operation than is common tin ; while, for the production of *grain tin,* the finest pigs are heated just below their melting point, and allowed to fall from a considerable height, when the metal breaks in the form of long grains.

Before the refining proper, the tin undergoes a process of *liquation,* that is, the pigs of tin are placed upon the bed of a reverberatory furnace similar to the last, except that the bed is made to slope rather more. About 18 tons of pigs are placed in the furnace and arranged near the bridge ; the temperature is raised and carefully regulated so as to be only sufficient to melt the tin without wholly melting the pigs, the tin then flows or liquates continuously away into the kettle, leaving on the furnace bottom a somewhat refractory and very hard mass, known as *hard-head,* into the composition of which enters about 50 per cent. of iron, 20 per cent. of tin, 20 per cent. of arsenic, 2 to 3 per cent. of sulphur, and a trace of copper. As the tin liquates or runs away, more pigs are added until the kettle has received its full charge. When the kettle, which is about 4 feet 6 inches in diameter, and heated by its own fire, contains about 7 tons of metal, billets of *green wood* (by preference the apple tree) are introduced and kept depressed, by the appliance previously mentioned, below the surface of the melted metal. The gases disengaged from the wood cause the tin to boil up, and a

skum consisting chiefly of iron, tin, and arsenic, or the same as that left on the furnace bottom after liquation, forms on the surface, and is skimmed off from time to time. The refining is from one hour to eight hours in duration, according to the amount of impurities present, and also whether common or refined tin is the object of the operation.

For *common tin*, the metal is ladled from the kettle into the moulds while the wood is still maintained beneath the surface, and fresh metal continues to run in from the furnace; but for *refined tin*, besides being made from the purer ores, the refining is continued longer, the wood is withdrawn, and the metal allowed to separate into layers before lading is commenced; the upper strata or layers, being the purer, are set aside for *grain tin*, the middle as *common tin*, while the lower are still so impur' as to require again liquating. The moulds into which the tin is ladled are usually made of granite, and the product is 'old as *block tin*.

Instead of the *boiling* or *poling* just described, a process of *tossing* is sometimes followed, that is, the melted tin is raised in ladles and allowed to fall for several feet through the atmosphere into the refining vessel, thus exposing a large surface to the cooling influence of the air, whereby the less fusible metal, *hard-head*, containing the impurities of the tin, separates and floats on the surface as a skum, which is removed while the purer tin liquates out. The scum or *hard-head* produced in this operation, has a similar composition to that left on the furnace bottom in the furnace liquation described.

If specimens of the metal, ladled into small stone ingot moulds, retain their bright clear surface with full rounded sides until cold, the metal may be classed as *refined* or *grain tin;* but if the metal, though bright when hot, acquires a frosted appearance at the moment of solidification, and is also not so round and full at the sides, it is classed as *common tin;* and should the metal have a yellowish tinge, and exhibit striae or a frosted appearance before solidification, it requires further liquation and refining.

In Germany, tin is still smelted in the blast furnace with charcoal as the fuel, and in this manner much of the purer tin, known as *grain tin*, is still produced; but the loss of

metal and consumption of fuel are much greater than in the reverberatory furnace, and hence its use has been altogether discontinued in England. The tin smelted in blast furnaces with charcoal as fuel, is reported, however, to be purer than when the reverberatory furnace is employed.

The furnace employed at Altenberg is a low blast furnace, built of large blocks of granite or porphyry, surmounted above by a hood, the blast being supplied by bellows; the ore, with reducing agent and flux, is introduced at the top, and in about four hours the metal begins to run from the tap-hole, the furnace being kept filled with smelting materials while the smelting operation continues. The metal and slag run out together
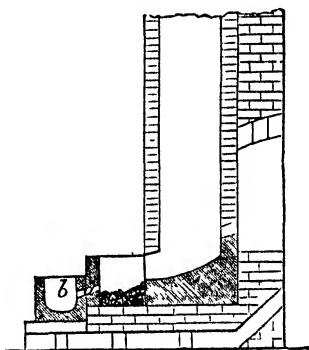
Fig. 53. — BLAST FURNACE FOR THE SMELTING OF TIN.

as the smelting proceeds, along a channel provided for the purpose into a basin; from which, as it fills, the slag which floats on the surface is passed down an incline *a* into another receptacle *b* full of water; after which treatment the slag is easily broken up for subsequent resmelting, the metal being tapped as the basin fills into another vessel at the opposite side to that which receives the slag.

166. Oxland's Process.—Wolfram, a tungstate of iron and manganese frequently present in tin ores, cannot be separated by any mechanical treatment, by roasting operations, or by treatment with acids, from the tin stone; and should it be present in considerable quantity, it renders the tin difficult to fuse in its reduction. The process patented by Mr. Oxland has for its object the removal of the wolfram from tin ores, by converting it into a soluble tungstate of soda, which can then be dissolved out by lixiviation. For this purpose the ore is treated with carbonate or sulphate of soda, in a reverberatory furnace of special construction; the

hearth of the furnace being formed by an iron pan, arranged so that the flame from the fireplace, after passing over the pan or hearth, is directed backwards beneath the pan to the chimney.   By the use of an iron pan, instead of a brick or other siliceous bottom, the formation of silicates of tin is prevented.   The charge of from 6 to 9 cwt. of ore is placed on the bed of the furnace, and from 9 to 12 cwt. of carbonate of soda or crude soda is spread over the heated ore, the mass being stirred or rabbled every fifteen minutes, and a quantity of coal is thrown to the back of the hearth about every half hour; in about six hours the operation is completed, and the pasty mass is drawn from the furnace, allowed to cool, and then broken up in the stamping mill into pieces of the size of an egg; to facilitate this disintegration, about 25 per cent. of quartz is added, which in the mill serves to break the hard alkaline crust formed around the pieces of tin ore.   The mass is now repeatedly washed, and the coarser portions re-stamped; and sometimes a second fusion with carbonate of soda is necessary.

If sulphate of soda be used instead of the carbonate, the loss of tin from the formation of stannates of soda is not so great, but the management of the process is more difficult, requiring greater care for the maintenance of the proper condition of the flame.   The charge of ore, sulphate of soda, or salt cake and small coal, is heated in a reverberatory furnace, a reducing flame being maintained until the sulphate of soda is reduced to sulphide of sodium, when a bright oxidizing flame is required to effect the decomposition of the sulphide, with the formation of tungstate of soda; after six hours the charge is drawn and thrown into a cistern of water, when the tungstate of soda is dissolved as before.

167. Tin and Iron. — These two metals have a great affinity for each other; in tin plates, at the junction of the tin and iron, there exists a true alloy of the two metals. Tin containing 2 per cent. of iron is magnetic, hard, and sensibly duller in lustre than pure tin.   Cast-iron alloyed with about 5 per cent. of tin is hard, and exhibits a steely fracture; and 0·5 per cent. of tin in malleable iron renders it hard and unworkable under the hammer in the cold state.   When an alloy of iron and tin containing an excess of the latter is

heated continuously, a portion of the tin will liquate from the alloy, and there remains behind a more or less infusible alloy of iron and tin, corresponding to the *hard-head* already mentioned under the refining of tin. An alloy of 80 parts of tin with 10 parts of iron has been proposed instead of pure tin for the tinning of copper utensils.

168. **Tin Plates.**—What are known as tin plates in commerce are thin plates of iron, coated or alloyed on their surface with metallic tin, the iron giving strength to the plate, while the tin prevents the rust or oxidation of the surface, which takes place when iron plates are exposed unprotected to the action of air and moisture. For the manufacture of these plates, and especially for the better qualities, the iron is subjected to a special refining, in which the fuel employed is entirely charcoal, the plates produced being known as *charcoal plates*. The manufacture of the iron plates for this purpose has been noticed under iron. and the treatment of the bars after leaving the refinery will only be described in this place.

The bars of refined iron are cut to the proper length for the size of plates to be produced, when the bars so obtained are heated to dull redness, and passed several times through a pair of narrow rolls; the plate thus produced is doubled upon itself, and a little coal dust introduced between the surfaces to prevent their adhering together, the ragged edges produced by the previous rolling are cut off, and, after heating, the doubled plate is again rolled; this operation of doubling over, reheating, and rerolling, is repeated until the plate has acquired the necessary thinness, the final plate consisting of 4, 8, 12, 16, or 32 thicknesses, leaving the rolls as though it were one plate; but the heat has been so regulated as to prevent the plates welding together except in odd and accidental cases. The several folds of the plate are now separated, and the *black plates* so obtained are passed to the *pickling* room, where they are immersed in warm dilute sulphuric acid, which, assisted by rubbing with sand and water, cleans the surface of the oxide of iron formed during the heating and rolling processes. The plates now require *annealing*, for which purpose they are packed into a cast-iron box about two feet square, air being carefully excluded by

requiring great care, the alloy is melted in reverberatory furnaces of special construction, with round or oval hearths, wood being employed as the fuel; when the copper, or copper and old bronze has been placed on the bed of the furnace, the heat is raised rapidly, the tin, as being most affected by oxidation, not being inserted until the copper is completely melted, when the tin is pushed to the bottom of the bath of molten copper, the surface of the fluid metals being covered with charcoal, and access of air to the hearth prevented as thoroughly as possible. The tin is introduced in the form of small pigs for the facilitation of its fusion, and the mass is continually stirred or poled with a pole of birchwood, to maintain the mass as liquid and homogeneous as possible; any scum rising to the surface is removed as it forms. In making bronze for statues or other objects, where strength and definite composition are not material, rough old copper, with adhering solder, etc., are frequently used, and hence the introduction of many impurities into bronze of this class.

171. Bell Metal. — This is an alloy of copper and tin, containing usually from 70 to 80 per cent. of copper. The bell at Westminster (Big Ben) was prescribed in the contract to consist of 76 per cent. of copper and 24 per cent. of tin. Antimony is occasionally found in bells, especially in the older specimens.

172. Speculum Metal.—This is a very hard, brittle, steel-grey alloy, capable of receiving a very uniform and highly polished surface; it contains about 30 per cent. of tin, or about two parts of copper to one part of tin; from 2 to 3 per cent. of arsenic is also sometimes added for the purpose of hardening it, and rendering it more susceptible of a high polish. Its composition on cooling, after fusion, remains more uniform than the previous alloys of copper and tin.

173. Pewter.—Pewter is a very malleable alloy of lead and tin, of very variable composition. The common variety is composed of 80 parts of tin to 20 of lead; while for plates, teapots, etc., the alloy is void of lead, but contains 89 per cent. of tin with 7 per cent. of antimony, and 2 per cent. of each of copper and bismuth,

174. Britannia Metal.—This is an alloy of tin, antimony, bismuth, copper, and zinc, in very variable proportions, which is highly malleable, and can be rolled out and spun into various shapes. In its preparation equal parts of plate brass, bismuth, antimony, and tin, are melted together, and the resulting alloy added to melted tin, until the proper colour and hardness for its desired use is obtained: that for spinning contains about 94 parts of tin, 5 of antimony, and 1 of copper; while for rolling the proportions of 90 parts of tin, 7 of antimony, and 3 of copper are added; while the metal for casting teapots, etc., in hollow moulds, consists of about 84 parts of tin, 10 of antimony, 4 of copper, and 2 of bismuth.

175. Tin and Zinc.—These alloy well together on fusion; the zinc increases the hardness, but lessens the ductility of the alloy.

176. Amalgam, etc.—The amalgam used for the rubbers of electrical machines, consists of 25 parts of tin, with 25 of zinc, and 50 of mercury. Gold forms a malleable alloy with pure tin, whose specific gravity is above the mean of its constituents; with silver, also, a white malleable and readily oxidizable alloy may be obtained.

177. Tin and Lead.—These metals alloy well together in all proportions, the metals not separating on cooling after fusion, as occurs when the lead is replaced by copper. Pewter, already mentioned, and *plumber's solder*, are alloys of this class; the hardness and tenacity of these alloys are at a maximum when the metals are present in the proportion of three of tin to one of lead. Plumber's solder varies in composition, containing from 30 to 60 per cent. of tin, the remainder being lead. *Type metal* is an alloy of equal parts of antimony and tin, with two of lead. *Fusible alloy* is a body which melts at 200° F., or below the temperature of boiling water, and is accordingly used for plugs and other purposes, where the temperature is required not to exceed this limit; it consists of eight parts of bismuth, four of lead, and four of tin; the addition of a little cadmium to this alloy constitutes *Wood's alloy*, which fuses at 145°F. or 63°C.

178. Tinned Pins.—Brass pins are coated with tin, by

boiling them with cream of tartar, common salt, alum, granu
lated tin, and water; the action is partly chemical and partl
electrical, the zinc of the brass separating the more electr
negative metal tin from its solution, and depositing it o
the surface of the pins.

Tinning of Copper. — The operation of tinning coppe
utensils or copper plates is very readily effected. For thi
purpose the surface of the copper plate is first rendere
smooth by rubbing it with a fine sandstone, after which th
plate is heated and its surface is rubbed over with salammonia
(NH$_4$Cl), the effect of which is to remove any oxide of coppe
from the surface of the plate, and to leave it perfectly clea
and bright; a small quantity of tin, or tin alloyed with leac
along with a little powdered resin, is now placed upon th
copper, and the plate is again heated, when the resin is th
first to melt, and coats the plate with a coating which pre
vents oxidation from the contact of the heated plate with th
atmosphere, when, as the tin melts, it is spread with a piec
of tow over the surface of the copper, to which it become
perfectly united.

CHAPTER XI.

ANTIMONY.

179. Properties.—Antimony is a bluish-white, very brittle metal, which crystallizes in the rhombohedral system, giving rise to the stellate or fern-like markings occurring on the surface of the metal as cast in the form of cakes; its density is about 6·8; it fuses at a temperature near 430°C., and is slowly volatilized at a white heat in an atmosphere of hydrogen; it is not sensibly altered by exposure to the atmosphere at ordinary temperatures, but at a red heat it burns with a bluish-white flame, with the production of thick white fumes of antimonious oxide (Sb_2O_3). Heated with strong sulphuric acid, sulphate of antimony is produced with the evolution of sulphurous anhydride (SO_2), while the dilute acid is without action upon the metal. It is rapidly oxidized without solution upon treatment with nitric acid, the degree of oxidation depending upon the concentration of the acid. Powdered antimony is attacked by boiling hydrochloric acid with the evolution of hydrogen, but in the massive state it is not affected by the treatment. Antimony and sulphur readily combine under the influence of heat. The chemical symbol of antimony is Sb, and its atomic weight is 122.

180. Impurities in the Metal.—The most frequent impurities occurring in *commercial antimony,* are sulphur, potassium, sodium, arsenic, lead, bismuth, iron, tin, silver, and traces of copper, the presence of small quantities of tin rendering the metal more largely crystalline. It may be freed from sulphur, arsenic, iron, and copper (but not lead), by fusing for an hour, in a Hessian crucible, a mixture of coarsely pounded antimony with $\frac{1}{8}$ of its weight of sodic carbonate and $\frac{1}{16}$ of its weight of grey sulphide of antimony, when the iron and copper are converted into sul-

phides, which in combination with sulphide of sodium passes into the slag, while the arsenic passes out as arsenate of sodium; after cooling and separation of the slag, the metal may be again fused with sodic carbonate for the further elimination of arsenic. The arsenic cannot be removed in this manner until the whole of the iron has been separated from the metal.

181. Oxides of Antimony.—As already stated, if antimony be heated in the atmosphere to a sufficiently high temperature it burns, producing white fumes of *antimonious oxide*, or *flowers of antimony* (Sb_2O_3); the same oxide is produced when steam is passed over strongly-heated antimony. Thus—

$$2Sb + 3OH_2 = Sb_2O_3 + 6H.$$
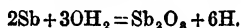
This oxide is a white powder, fusible and volatile at a red heat, subliming without change if heated out of contact with the air, but passing to a higher state of oxidation if kept fused with contact of the air; it is soluble in tartaric acid, yielding *tartar emetic*, and on treatment with nitric acid or potassic chlorate, it is converted into a higher oxide. Antimonious oxide is reduced to the metallic state when heated to a red heat with carbon, or if carbonic oxide or hydrogen be passed over the heated oxide; it is also reduced by heating with cyanide of potassium; and zinc, tin, or iron precipitate the whole of the antimony from solutions of this oxide. When an antimony salt is treated with zinc and a dilute acid, a portion of the liberated hydrogen escapes in combination with antimony as antimoniuretted hydrogen (SbH_3), which is decomposed, like the corresponding arsenic compound, at a red heat with the deposition of metallic antimony.

The *tetroxide of antimony* (Sb_2O_4) occurs native as *cervantite* or *antimony-ochre*, and it is formed when antimony or antimonious sulphide (Sb_2S_3) is heated in the atmosphere, or by the action of heat upon antimonic oxide (Sb_2O_5), when it forms a powder which is yellow while hot, but white when cold. This oxide is reduced by carbon, but in this case the addition of a little carbonate of soda is necessary in order to collect the metal.

The highest oxide of antimony is *antimonic* oxide or

anhydride (Sb_2O_5), which at a red heat is resolved into the last-mentioned oxide and free oxygen. The pigment known as *Naples yellow* is an antimoniate of lead.

182. Sulphides of Antimony.—There are two sulphides corresponding to the two principal oxides of antimony; but the *antimonious sulphide* (Sb_2S_3) is the only one of metallurgical interest; it occurs native as the minerals *stibnite* or *grey antimony ore, antimony glance,* etc., or it may be prepared artificially by melting sulphur with antimonious oxide, when sulphurous anhydride escapes, and antimonious sulphide is left, on cooling, as a crystalline mass.

$$2Sb_2O_3 + 9S = 2Sb_2S_3 + 3SO_2.$$
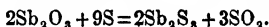
By roasting this sulphide at a temperature below its fusing point, sulphurous anhydride is evolved, and antimonious with antimonic oxide remain. It is decomposed by carbon at a high temperature, with the evolution of sulphide of carbon and separation of metallic antimony; it also suffers decomposition at a red heat when in contact with *tin, iron, copper, potassium,* or *sodium,* with potassic cyanide (KCy), or with a mixture of carbonate of potassium or sodium with charcoal, the resulting sulphide combining with the excess of antimonious sulphide; or if the reducing metal be in excess, it occasionally alloys itself with the reduced antimony. Steam passed over antimonious sulphide liberates sulphuretted hydrogen (SH_2), and an orange-yellow body sublimes, containing antimonious oxide and sulphide. A violent reaction ensues when antimonious sulphide is fused with nitre; the sulphur and antimony being oxidized with the formation (if the nitre be in excess) of sulphuric acid and antimonic oxide. Antimonious sulphide is decomposed by hydrochloric and nitric acids.

183. Antimony Glass.—This is an artificial oxysulphide of antimony, varying in colour from a yellowish-red to a hyacinth-red; it is prepared by converting the grey sulphide of antimony into oxide by roasting at a moderate heat, then fusing this product, known as *antimony ash,* in an earthen crucible with about $\frac{1}{20}$ of its weight of sulphur.

184. Livers of Antimony.—This is a black or brown-black crystalline sulphantimonite of potassium, prepared by fusing antimonious sulphide (Sb_2S_3) with sulphate of potash

and charcoal, or by melting the sulphide with an alkaline carbonate, sulphur, and charcoal.

185. Ores.—Antimony occurs *native,* alloyed with arsenic, nickel, silver, and iron; in combination with oxygen as *antimony bloom* or *valentinite,* and as *antimony ochre* or *cervantite;* but the chief ore, and that from which the antimony of commerce is extracted, is *stibnite* or *grey antimony ore,* the sulphide of antimony (Sb_2S_3), which often contains also copper, iron, and arsenic; this ore occurs associated with gneiss, quartz, clay-slate, mica-slate, limestone, heavy-spar, etc., in Borneo, Hungary, Germany, Bohemia, France, Cornwall, and the United States. Sulphide of antimony, along with sulphide of silver, occurs in *ruby silver;* and *red antimony* is a mixture of the oxide and sulphide of antimony occurring in Tuscany. Antimony likewise occurs frequently as a constituent of numerous other minerals, and ores of other metals, particularly with lead and silver, as in Jamesonite, Bournonite, and Miargyrite, and with copper in antimonial copper, etc., but these cannot be considered as ores of antimony.

186. Reduction.—The *crude* antimony of commerce is merely the sulphide, freed by a process of *liquation* from the gangue or vein stuff accompanying the ore, and for this purpose the ore in not too small pieces is heated, either in conical pots, perforated at the bottom and having a receiver beneath each of them, or on the inclined bed of a reverberatory furnace, the liquated sulphide of antimony being conveyed along channels in the bed to a receiver outside the furnace. In either case the temperature must not be too high, but requires careful regulation, otherwise the sulphide of antimony softens and forms a pasty mass with the gangue of the ore, from which the antimony cannot be readily liquated. The pots first mentioned may be heated in a reverberatory furnace with the receivers placed beneath the hearth, or in a furnace (fig. 54) as used at Malbose in France, and known as "Penserat's Furnace," in which the cylinders or pots *a, a,* perforated at the bottom, stand on plates similarly perforated, and beneath each of which is a small oblong chamber containing the cast-iron receiving pots *b, b,* lined with clay; four of these cylinders are arranged in one furnace, with the

fire-bars from back to front on each side of, and between the pots; the charge of the cylinders is introduced from the top, the furnace being surmounted by the hood *d*, with openings, as shown, for gaining access to the tops of the cylinders. The charge of 5 cwt. of ore is introduced into each of the cylinders, and wood fires first made on the grates, subsequently supplied with a little coal; the sulphide or crude antimony melts and *liquates* out into the receivers beneath, the operation being completed in about three hours, with the production of about $2\frac{1}{2}$ cwts. of *crude* antimony, containing from 60 to 70 per cent. of metallic antimony, with lead in variable proportions up to 10 per cent., a little iron, traces of arsenic, and from 25 to 30 per cent. of sulphur.
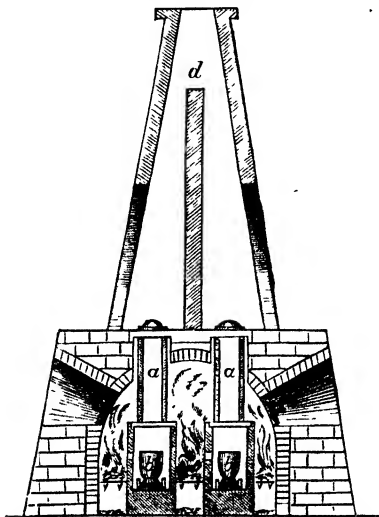
Fig. 54.—PENSERAT'S FURNACE FOR THE SMELTING OF ANTIMONY.

In France, in the department of Ardèche, where fuel is cheap and abundant, the pots, instead of being placed in a furnace, are arranged in rows of twenty-five or thirty each, between two walls about 9 inches in height, each pot standing upon a receiver sunk in the ground, the space between

the pots being filled with fuel. A construction of this kind works off a melt in about ten hours, and four melts suffice to fill each receiver with the crude metal.

To separate the *metallic* antimony from the *crude* antimony obtained in these processes, it is heated to bright redness, along with iron filings, nails, or small scrap-iron, as clippings of tin plates, etc., in covered crucibles heated in reverberatory furnaces, being careful that the antimonious sulphide is always in excess, otherwise any excess of iron is alloyed with the reduced antimony. A very gentle heat suffices to effect the decomposition, but a somewhat higher temperature is required to collect the metallic antimony into a distinct stratum in the crucible; the decomposition is formulated in the following equation:—

$$Sb_2S_3 + 3Fe = 3FeS + 2Sb.$$
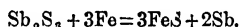
It is further necessary to fuse this product with sodic carbonate, nitre, or borax, or these substances along with a little charcoal, whereby a readily fusible double sulphide of iron and potassium or sodium is formed, while the antimony separates readily. For the separation of the last traces of sulphur, arsenic, iron, and copper, the product is subjected to a second or third fusion with carbonate of soda, antimonious oxide or potashes (crude carbonate of potash), when the metal is cast into large circular moulds with rounded bottoms, in which it is allowed to cool under a layer of a very fusible slag, or under a stratum of melted tallow, when the surface of the cake should present the appearance of fern-leaf crystals.

Instead of the above methods of *reduction by iron*, the metal may be reduced from its sulphide by roasting in a reverberatory furnace at a dull red heat, and fusing the roasted ore with charcoal and an alkaline flux. In the roasting, sulphur and arsenic are expelled as sulphurous anhydride (SO_2), and arsenious anhydride (As_2O_3) respectively, which are accompanied with a little antimonious oxide (Sb_2O_3), the two latter condensing in the flues; and there remains a reddish-brown residue of the mixed sulphide and oxide of antimony, which is reduced to powder and mixed with about $\frac{1}{4}$ of its weight of charcoal, and the like amount of carbonate of soda, sodic chloride, or sulphate of soda, and slags from a previous operation, or with a mixture of coal

and potassic carbonate; this mixture is then heated upon the bed of a reverberatory furnace or in crucibles, when the metal known then as "REGULUS OF ANTIMONY" separates beneath a layer of slag or flux, consisting of the sulphides of antimony and sodium or potassium, the slag so obtained constituting the product known in commerce as "CROCUS OF ANTIMONY." The metal prepared in this manner is purified, as in the "iron reduction process," by fusion with nitre.

In England, when smelting rich ores, the "regulus of antimony" is separated *direct* from the ore (without the preliminary liquation first described) by introducing the broken ore into red-hot crucibles, and placing upon the charge so introduced a layer of an alkaline flux, and lastly scrap-iron is pressed down upon the mass; upon melting, the iron is mixed with the mass, and in from two to two and a half hours the reduction is complete, and the contents of the crucibles are poured into moulds, the metal collecting as the lowest stratum, above which is a layer of ferrous sulphide, and on the top an alkaline slag.

187. Alloys.—The effect of antimony is to harden the metals with which it is alloyed, and generally to *impair* the malleability and ductility of the malleable metals. Antimony is alloyed with the softer metals, as lead and tin, to harden them; *stereotype* metal, an alloy of this class, consists of lead with about $\frac{1}{5}$ of its weight of antimony, and a small proportion of tin. Alloyed with tin, and occasionally bismuth, it constitutes the varieties of Britannia metal and Pewter, as described under alloys of tin; and an alloy consisting of 80 parts of tin with 20 of antimony constitutes the metal employed for music plates; while an inferior kind of Britannia metal, known as "Queen's Metal" is an alloy formed of 75 parts of tin, with 8·5 of antimony, 8 of bismuth, and 8·5 of lead. Copper and antimony alloy well together, producing a crystalline violet body, of no use in the arts, 0·15 per cent. of antimony in copper rendering the latter both hot and cold short. The presence of 0·5 per cent. of antimony in fine gold renders it quite brittle, and even ·05 per cent. of this metal injures its malleability. The presence of 0·1 per cent. to 0·3 per cent. of antimony in malleable iron makes it both hot and cold short. Lead containing

antimony is notably hard, and there is little, if any, commercial lead absolutely free from this impurity; the operation of softening lead, described when treating of that metal, has for its object the removal of the antimony by the joint action of heat and air upon the alloy, the more ready oxidizability of the antimony permitting of its removal by simple heating of the alloy in contact with air, when a scum rises to the surface consisting largely of oxide of antimony and antimoniate of lead, with a small proportion of oxide of lead and some metallic lead. An alloy of antimony, lead, and mercury is harder than lead, while retaining its ductility; an alloy of this kind has been patented for use as ships' sheathing, to prevent fouling of the bottoms.

CHAPTER XII.

ARSENIC.

ARSENIC is an element of a steel-grey colour, with a metallic lustre, crystallizing in rhombohedra, and a specific gravity in the solid state of from 5·62 to 5·96; it has never been seen in the fluid state, volatilizing at a dull red heat without previous fusion, and evolving a powerful odour resembling that of garlic; its behaviour on exposure to the air depends much on the temperature employed in, and the mode of, its preparation; if the metal be obtained as a dark-grey crystalline powder, such as forms in the cooler parts of the condensing apparatus employed in its sublimation, or as it occurs when reduced from arsenious acid (As_2O_3) by charcoal, and condensed while its vapour is still mixed with carbonic oxide, etc., then it oxidizes rapidly on exposure; but if the metal be obtained as a compact whitish mass, such as forms in the parts of the apparatus where the temperature is only just below the point of volatilization of the arsenic, then the metal is scarcely affected by exposure to the atmosphere. Under the joint influence of heat and air, arsenic burns with a blue flame, producing arsenious anhydride (As_2O_3). Heated with sulphur, and combination ensues with the formation of the red compound known as "realgar" (As_2S_2). Arsenic frequently occurs in small quantities as an impurity in other metals, as in zinc, copper, tin, antimony, etc., producing hardness and brittleness therein. Its chemical symbol is As, and its atomic weight, 75. The metallic character of this element is not accepted by many chemists, since, in its chemical combinations, it resembles phosphorus and nitrogen, and possesses no basic oxide; yet in physical characters, as lustre, specific gravity, conductivity for heat, and electricity, etc., it re-

sembles the metals, especially antimony and bismuth, and it would thus appear to form the connecting link between the metallic and non-metallic elements.

188. Ores.—Arsenic in minute quantities is very widely distributed, occurring occasionally in the *native* state, but more frequently in combination with other metals, as in *arsenical iron;* with *sulphur* as *realgar* (As_2S_2) and *orpiment* (As_2S_3); or in combination with sulphur and iron, cobalt, nickel, or other metals; it thus occurs in *arsenical pyrites* or *mispickel* (FeAs + FeS₂); other ores containing arsenic are, *smaltine* or *tin-white cobalt, arsenical cobalt, cobalt glance, nickel glance, arsenical fahl-ores, kupfernickel* or *arsenical nickel, white nickel pyrites* (NiAs), *copper nickel* (Ni_2As) and *arsenic bloom.*

189. Preparation.—Arsenic is obtained on the large scale by heating *mispickel* or *arsenical pyrites* (Fe_2AsS) in earthen tubes or retorts, four or five feet in length, which are laid horizontally in a long furnace, a nozzle being formed of sheet-iron, rolled to fit the end of the retort, to which is luted an earthen receiver; when, on the application of a moderate heat, metallic arsenic sublimes as a compact, nearly white, crystalline body, requiring a further purification by resublimation before use, except where intended for the preparation of common alloys, when the crude product so obtained is directly employed; there remains in the retort, after the operation, a mass of sulphide of iron ; thus,

$$Fe_2AsS = Fe_2S + As.$$
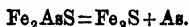
At Altenberg, in Silesia, arsenic is prepared by heating in crucibles, surmounted by conical iron caps, the crude arsenious acid (As_2O_3) (obtained as a bye product during the roasting of tin and cobalt ores) along with charcoal; and it may also be obtained by heating the sulphides of arsenic with charcoal and potassic cyanide, or an alkaline carbonate.

190. Arsenious Acid.—*Arsenious acid, arsenious anhydride,* or *white arsenic* (As_2O_3), exists either as an amorphous solid, or crystallized in octahedral and rhombic forms. The amorphous variety when first prepared is transparent and vitreous, but on exposure to sunlight gradually becomes

opaque and crystalline; in the vitreous form it may be fused before volatilization, but the crystalline variety sublimes at a temperature of 218° C. (474° F.), without previous fusion. Arsenious oxide is only sparingly soluble in cold water, but dissolves more readily in boiling water, and is still more soluble in hot *dilute acids*, from which solution the acid separates on cooling; by boiling with nitric acid or aqua regia, it is converted into *arsenic acid; carbon, carbonic oxide*, or *hydrogen*, reduce metallic arsenic from arsenious anhydride at a temperature below redness; arsenious anhydride is also decomposed by nascent hydrogen, yielding arseniuretted hydrogen (AsH_3), a highly poisonous gas; thus,

$$As_2O_3 + 12H = 3OH_2 + 2AsH_3.$$
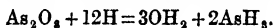
Metallic copper immersed in a hot solution of arsenious acid (As_2O_3), or an arsenite made acid by hydrochloric acid, becomes coated with a grey film of metallic arsenic; zinc behaves in a similar manner, but a portion of the reduced arsenic combines with the nascent hydrogen, which yields arseniuretted hydrogen, while the residue only is deposited on the zinc. Arsenious acid enters into the composition of the brilliant green pigments known as *Scheele's green*, and *Schweinfurt, Emerald or Imperial Green;* the former is an arsenite of copper formed when *arsenious acid* or an *alkaline arsenite* is added to a soluble salt of copper, with sufficient ammonia to neutralize the acid. The *Schweinfurt green* is an aceto-arsenite of copper, prepared on the large scale by making five parts of the basic cupric acetate, known as *verdigris*, into a thin paste, and adding it to a boiling solution of four parts of arsenious anhydride in fifty of water kept boiling during the mixing of the ingredients and the precipitation of the pigment; it is then cooled, dried, powdered, sifted, and rubbed with a little hydrochloric acid, when it is ready for use as a pigment.

Arsenious acid, or anhydride (As_2O_3), is obtained as a secondary product in the roasting of arsenical ores of tin, cobalt, and nickel; also in the roasting of argentiferous native arsenic for the extraction of silver; but the largest supply is obtained by the roasting of powdered *arsenical pyrites* or *mispickel,* with access of air, when *arsenious*

anhydride sublimes, and is condensed in long flues or chambers. If the operation be performed on the bed of a reverberatory furnace, the arsenious anhydride, as collected, is mixed with carbonaceous matter, and on the resublimation of the product, the carbon present reduces a portion of the anhydride to metallic arsenic, and the final product, instead of being perfectly white, is grey, from the admixture of metallic arsenic ; it is hence more usual to effect the roasting in muffle furnaces, which prevent the contact of the flame or fuel with the products of the roasting operation. A furnace of this kind has two floors, one above the other : on the upper one is spread the ore to be roasted ; a door at the front of this chamber affords access for rabbling the mass, while the fire-bars are at the near end of the lower bed, the products of combustion before reaching the stack being made to pass beneath the upper floor to its extremity, and thence backwards along each side of the upper chamber; the upper floor is charged through an opening in the top, and the arsenious anhydride, with other volatile matters, pass along flues or long divided passages, which open finally into a large chamber, some 120 feet in height, before reaching the stack ; the condensing flues in Cornwall are 600 feet in length, 6 feet high, and $2\frac{1}{2}$ feet wide, arched over at the top. At Altenberg, in Silesia, the volatile matters are passed through two or three large chambers, from whence the uncondensed portions are passed through some three floors of chambers, divided by partitions so as to increase the cooling surface; in these latter, known as the "poison towers," the last traces of arsenious anhydride are deposited, and only the non-condensible sulphurous anhydride (SO_2) escapes to the atmosphere. The chambers are only emptied every one or two months, the workmen, during the operation, being clothed in leather, with their mouths and nostrils protected by wet cloths ; the product collected from near the stack end of the condensing apparatus is more largely contaminated with sulphide of arsenic, and other impurities, than that deposited in the earlier parts of the course near the furnace, and the former accordingly requires resublimation.

The resublimation is effected in Silesia in a series of deep

cast-iron pots (fig. 55), each of which is charged with about 3 cwt. of the crude acid and heated over its own fire d, and surmounted by a conical cap b, communicating with a pipe which conducts the vapours to a large condensing chamber c, divided in the manner of our sulphuric acid chambers, and placed well above the subliming apparatus; the joints being all well luted up, a gentle heat is first applied for about half an hour, when the full heat is attained and continued for about twelve hours, when the arsenious anhydride will be wholly sublimed into the top portion of the retort, and into the condensing chamber. In Cornwall, a much simpler arrangement is employed, consisting of a cast-iron pot $3\frac{1}{2}$ inches deep and 22 inches internal diameter, with a bottom $3\frac{1}{2}$ inches in thickness; this pot is surmounted by a conical covering about 18 inches in height, and with an opening of about two inches in diameter; each of these vessels is heated by its own fireplace, or upon a sand bath, when the arsenious anhydride sublimes and condenses in the top of the cone.

Vertical Elevation   *Vertical Section.*

Fig. 55.—REICHENSTEIN ARSENIC REFINING FURNACE.

191. Arsenic Anhydride (As_2O_5) may be obtained by heating its hydrate to dull redness, when it forms a white mass, without action on litmus, nearly insoluble in water, only deliquescent after long exposure, and decomposed at a full red heat into *arsenious* anhydride and free oxygen; it is reduced to the metallic state by carbon, potassic cyanide, etc.

Fig. 56.—CORNISH APPARATUS FOR SUBLIMING ARSENIOUS ANHYDRIDE.

192. Hydrated Arsenic Oxide or **Arsenic Acid** may be

19—I.

obtained as a syrupy liquid by treating arsenious anhydride with concentrated nitric acid, this liquid, after standing some time, depositing crystals which are very deliquescent; this acid is now extensively used instead of tartaric acid by the calico printer; it combines with bases forming a class of tribasic salts known as *arsenates*.

193. Sulphur and Arsenic.—The only compounds of sulphur and arsenic of metallurgical interest, are the *disulphide* or *realgar*, and *arsenious sulphide* or *orpiment*.

Disulphide of arsenic or *realgar* (As_2S_2), as already stated, occurs native as an orange-yellow or red mineral, more or less translucent, and possessing a resinous lustre; it occurs, accompanying ores of silver and lead, at Andreasburg, in the Harz, in Transylvania, Hungary, Bohemia, and Saxony. Realgar is prepared, on the large scale, by heating a mixture of arsenical and iron pyrites, collecting the sublimate and melting it with arsenic or sulphur, according to the intensity of the colour required; as thus produced it is amorphous, brown-red in colour, opaque, and burns in the atmosphere with a blue flame, with the production of sulphurous and arsenious anhydrides. This compound is used in pyrotechny, and also as a pigment.

The *trisulphide of arsenic* or *orpiment* (As_2S_3) also occurs native. As prepared for commerce, by the sublimation of a mixture of seven parts of arsenious anhydride (As_2O_3) with one of sulphur, it is translucent, of a lemon-yellow colour, and possesses a resinous lustre. Orpiment is produced as a lemon-yellow precipitate when sulphuretted hydrogen is passed into a solution in dilute hydrochloric acid, of arsenious anhydride or an arsenite. This sulphide melts readily, and volatilizes at a higher temperature; when heated in a glass tube with sodic carbonate or cyanide of potassium and an alkaline carbonate, it yields a mirror of metallic arsenic on the cooler part of the tube; the residue consisting, when sodic carbonate is employed, of sulpharsenate and arsenate of soda, when, if carbon be introduced into the mixture, the arsenate suffers decomposition, and the mirror of arsenic is increased. This sulphide of arsenic constitutes the pigment "King's yellow."

194. Alloys.—Arsenic alloys itself with most of the other

metals: with *iron, zinc, tin, gold, silver, lead,* and *antimony,* it forms alloys which are more or less brittle and hard; it is especially destructive of the malleability of gold, while with copper a white malleable alloy can be obtained. The alloy of arsenic and lead is used in making shot, and in the preparation of some forms of opal glass. Analyses of two specimens of *shot,* published by Dr. Percy,* show it to contain 0·133 per cent. and 0·115 per cent. of arsenic respectively, the same shots containing respectively 0·03 per cent. and 0·284 per cent. of copper. The alloys of arsenic, when heated out of contact with the atmosphere, retain almost the whole of their arsenic, while if heated with access of the atmosphere, part of the arsenic is volatilized as arsenious anhydride (As_2O_3), leaving a residue of a metallic *arsenate* or *arsenite;* but the alloy of *antimony* and *arsenic,* heated in an atmosphere of carbonic acid is completely decomposed, with the volatilization of the arsenic. Arsenic lowers the melting point of the metals with which it is alloyed.

* Percy, Vol. III.

CHAPTER XIII.

BISMUTH.

This metal was known to the ancients. Although not of frequent occurrence in nature, it is, however, found associated with ores of nickel and cobalt in Cornwall and Cumberland, and in the extraction of the latter metals, bismuth is generally obtained as an accessory product.

Bismuth is a greyish-white metal, having a decided reddish tinge, with a bright metallic lustre, not sensibly altered by exposure to the atmosphere; but if heated in the air it is readily oxidized, and at a higher temperature burns with a bluish flame, emitting yellow fumes of *flowers of bismuth*. It crystallizes in rhombohedrons, is very brittle, and easily reduced to powder; its specific gravity is 9·779, which, after subjecting the metal to considerable pressure, is reduced to 9·556. Bismuth is strongly diamagnetic; it fuses at 264°C. (507·2°F.), and expands on cooling, so that the density of the metal in the liquid state is greater than in its solid form; at a high temperature it may be volatilized or distilled, and at a white heat it decomposes the vapour of water. Hydrochloric acid has but little action upon the metal, and sulphuric acid only attacks it when hot and concentrated; while nitric acid forms its best solvent, attacking the metal vigorously, with the production of a nitrate of bismuth, which, on dilution with water, precipitates an insoluble basic nitrate of bismuth, and which precipitate, by reduction with black flux at a gentle heat, yields bismuth free from the impurities—arsenic, sulphur, copper, nickel, iron, silver, and gold, which sometimes accompany *commercial* bismuth. Specimens of commercial bismuth occasionally contain as much as 60 oz. of silver per ton of metal. Bismuth can be used instead of lead in the process of *cupellation,* to be described under lead, but is not quite

so readily oxidizable as lead. The chemical symbol of bismuth is Bi, and its atomic weight 208.

195. Ores of Bismuth.—As *needle ore* or *bismuth lead ore*, it occurs in Siberia and elsewhere, as *bismuth glance* or *bismuthine* (Bi_2S_3), in Cumberland, Cornwall, Saxony, Sweden, and the United States, and as *bismuth ochre* (Bi_2O_3), along with iron and other impurities, it occurs in Saxony, Bohemia, etc.; while the *native* metal is found in Saxony, Sweden, Norway, Hessia, etc., accompanying the ores of cobalt, silver, lead, copper, and tin; and, as already noted, bismuth occurs associated with the ores of nickel and cobalt in Cornwall and Cumberland.

196. Bismuth with Oxygen and Sulphur.—Bismuth forms three compounds with oxygen, but the most stable oxide is the bismuthous oxide or (as it was formerly termed) teroxide (Bi_2O_3), which occurs as a pale lemon-yellow powder when bismuth is roasted with access of air, or when the subnitrate is gently heated in a crucible. This oxide becomes darker in colour on the application of heat, and fuses at a strong heat forming a glass, which, on cooling, is of a deeper tint than the unfused oxide. Oxide of bismuth is reduced by heating with carbon. The hydrated oxide ($Bi_2O_3,\ H_2O$) is precipitated as a white powder when ammonia in excess is added to a soluble salt of bismuth.

Bismuth unites readily with sulphur, upon the application of heat. The tersulphide (Bi_2S_3) is thus obtained as a dark grey solid of metallic appearance; the same sulphide is also obtained as a brown black precipitate when sulphuretted hydrogen is passed through a solution of a bismuth salt.

197. Extraction.—For the purposes of the arts, bismuth is separated by simple *liquation* from the other matters accompanying the metal. The earliest plan adopted for this purpose was to make heaps of the ore and fuel upon the ground; a steady, gentle heat was thus maintained, and the bismuth liquating or sweating out was collected at the bottom of the heap. The supply of bismuth is now derived largely from Saxony, where the metal occurs *native*, associated with ores of cobalt, silver, lead, and tin, in formations of gneiss and clay slate; as also in ores of nickel and cobalt, with arsenic. At Schneeberg, in Saxony, the cobalt ores, containing about

twelve per cent. of bismuth, are first crushed and then subjected to liquation in the furnace shown in fig. 57, consisting of an arched chamber, in which are arranged a series of iron tubes or retorts, inclining from back to front; beneath the retorts is the fireplace, and in the roof of the furnace are two holes over each retort, which can be opened and closed as required for the proper regulation of the draught; at the back of the furnace, and from the upper end of the retorts, the brickwork forms a slope downwards to a trough filled with water, into which the residues from the retorts are withdrawn after the conclusion of the liquating process; the lower end of each retort is closed with an iron plate, containing a small aperture at the lowest point, through which the melted bismuth passes into the iron basins as shown, where it is kept in a state of fusion by a fire beneath the dishes, and the surface of the metal kept from oxidation by a covering of small charcoal. Wood is the fuel usually employed in this furnace, but gas has also been employed.
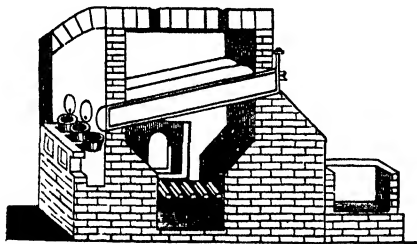
Fig. 57.—BISMUTH LIQUATION FURNACE.

The retorts are each charged from the upper end, with about 56 pounds of ore, when, if the furnace be hot from the working off of a previous charge, the metal will begin to pass out at the bottom in about ten minutes after charging; a gentle fire is maintained on the grate, a *low* temperature, about 265° C., sufficing for the liquation of the metal; and to facilitate the passage of the melted metal towards the lower end, the charge is moved about by a small rake introduced through the door at the upper end of the retort, and in about forty minutes from the commencement the whole of

the bismuth will have separated from the gangue and other metalliferous matters accompanying the metal, which residues are then raked out at the back, and slide down the incline into the water trough. The metal collected in the basins is then ladled out into moulds, forming bars of from 20 lbs. to 50 lbs. in weight.

At Joachimsthal,[*] Vogel treats ores of nickel and cobalt containing from 10 per cent. to 30 per cent. of bismuth, with from 25 per cent. to 30 per cent. of small pieces of iron, 15 per cent. to 50 per cent. of carbonate of soda, according to the amount of gangue present, 5 per cent. of lime, and 5 per cent. of fluor spar. This mixture is introduced into crucibles some 23 inches in height and 16 inches in diameter, heated in wind furnaces, when the bismuth separates and forms a layer in the bottom of the crucible, above which is a stratum of *speiss* (a metallic-looking compound containing nickel, cobalt, iron, arsenic, and sulphur, with traces of other metals). The bismuth, after again fusing, is ladled out into conical moulds.

The metal thus obtained is often very impure, containing sulphur and traces of arsenic, copper, nickel, iron, and lead, with variable amounts of silver; if required pure, the commercial metal must be treated, as already described, with nitric acid. It is freed from sulphur and arsenic, but not from lead, iron, or silver, by fusing with about one-tenth of its weight of nitre, with continual stirring of the mixture, by which treatment the impurities collect as a slag on the surface of the metal; if necessary, the fusion with nitre must be repeated a second time. The silver can be separated by *cupellation*, and the oxide of bismuth so produced subsequently reduced by charcoal in earthen crucibles.

198. Alloys.—The effect of bismuth when alloyed with other metals is usually to form more or less readily fusible bodies, which expand on solidification after fusion. The alloy known as *fusible metal* melting at about 93·75°C., or below the boiling point of water, consists of equal parts of lead and tin, with two parts of bismuth, and owing to the expansion produced in this alloy on cooling, it is much used for taking casts or copies of dies or other bodies. The addition of a

* Kerl. Handbuch der Metallurgischen hüttenkunde.

small amount of cadmium to this alloy, constitutes it what is known as "Wood's alloy," which melts at a still lower temperature, viz., 82°C., or 180°F.

An alloy of two parts of lead with one of bismuth fuses at 116° C., is ductile, and may be rolled without cracking (Berthier). An alloy of three parts of lead with two of bismuth is said to have about ten times the tenacity of lead alone. The density of these alloys is above the mean of the constituent metals.

Bismuth and mercury amalgamate by simple trituration at the ordinary temperature, the amalgam retaining a considerable amount of bismuth without losing its fluidity; mercury and bismuth, gently heated together, yield a fluid alloy if the bismuth be not in too large quantity; with two parts of mercury to one of bismuth the amalgam is pasty, and after standing hardens, and becomes more or less crystalline. The adulteration of mercury by bismuth may be detected by shaking the metal with air, when, if bismuth be present, a crystalline black powder separates.

Arsenic or antimony, when alloyed with bismuth, yield products which are brittle, and expand considerably on cooling.

Equal parts of bismuth and silver, fused together, yield a brittle, scaly alloy, of a reddish tinge, which may be cupelled with the separation of the whole of the bismuth as bismuthic oxide, exactly as with lead. In the same manner cupellation of the alloy of gold and bismuth may be effected.

Bismuth is a constituent of Britannia metal, as detailed when speaking of alloys of tin, an inferior kind known as "Queen's Metal," consisting of 75 per cent. of tin, 8·5 per cent. of antimony, with 8·5 per cent. of lead, and 8 per cent. of bismuth; and pewterer's solder consists of equal parts of lead and bismuth alloyed with two parts of tin.

The presence of only ·6 per cent. of bismuth in copper is sufficient to make the metal crack in the edges on rolling.

CHAPTER XIV.

PLATINUM.

THIS metal ranks next to silver in whiteness, and when polished it has a very strong metallic lustre; it is very malleable and ductile, being only inferior to gold, silver, and copper in malleability, and to gold and silver in ductility, while in tenacity it is only exceeded by iron and copper. The pure metal is softer than silver, it does not oxidize by exposure to the atmosphere at any temperature, and expands less by heat than any other metal; hence its employment for fusing into glass in the manufacture of philosophical and other instruments requiring the insertion of metallic connections through the substance of the glass; while in conductivity for heat and electricity it is much inferior to either gold or silver, in this respect ranking about equal with iron. It is infusible in the strongest heat of a smith's fire, but may be fused by the electric current, or by the oxyhydrogen blowpipe; at a high temperature the metal can be *welded* by pressure or hammering, as is exemplified in the condensation and welding together of the particles of spongy platinum; and with the exception of osmium and iridium, it is the heaviest of all known substances, its specific gravity varying from 21·25 to 21·5, according to the mechanical treatment it has received.

Platinum resists the action of most chemical agents, it is not attacked by hydrochloric, sulphuric, nitric, hydrofluoric, or any other single acid, except when alloyed with a large proportion of silver, under which circumstances it is soluble in nitric acid, a quality made use of in the assay of gold, for the separation of the platinum with which the gold is frequently alloyed; in nitro-hydrochloric acid (*aqua regia*), platinum dissolves slowly. These qualities of with-

standing the action of chemical agents, coupled with the power of resisting high temperatures, together with its non-oxidizability at all temperatures, make it a valuable material for the construction of crucibles, dishes, foil, wire, etc., used in the chemical laboratory for blowpipe and other experiments, as also for the manufacture of the *stills*, *syphons*, etc., employed in the concentration of sulphuric acid; and of the vessels employed in the method of *parting* gold and silver by sulphuric acid, as described under these metals; and from its power of resisting corrosion, it has been used for the touch-holes or vents of rifles and large ordnance, but its cost prevents its general adoption for this purpose. The hammered metal is only slowly attacked when strongly heated with sulphur; but phosphorus or arsenic under like conditions unite with the metal, with the formation of a readily fusible compound.

A mixture of silica and carbon cannot be exposed to a high temperature in platinum vessels, since the reduced silicon attacks the metal rapidly, with the formation of a fusible silicide of platinum; and for the same reason platinum vessels are never heated in contact with coke or charcoal, which always contain more or less silica, but are either heated in a gas flame, or, if required to be inserted into a coke fire, are enclosed in a receiver of some refractory material, as magnesia, etc.; nitre, caustic alkalies, alkaline earths, and acid potassic sulphate also attack it at high temperatures. Like silver, it absorbs oxygen when in the fused state, liberating it again as it cools, and if cooled rapidly, it *spits* or *sprouts* like silver (Deville and Debray) under the same circumstances. Platinum possesses the remarkable property of effecting the combination of oxygen and hydrogen, and of some other combustible gases into mixtures of which it is introduced, but this quality, known as *catalysis*, is more powerfully exercised by the metal in its *spongy* form, or as *platinum-black*; it forms two oxides, chlorides and sulphides, none of which are, however, of metallurgical importance. The chemical symbol of platinum is Pt, and its atomic weight is 197·4.

199. Platinum-black.—Platinum in an extremely fine state of division forms a black powder known as platinum-

black, which resembles lamp-black in appearance, and in which form it possesses some most remarkable and powerful chemical qualities. Platinum-black soils the fingers, and is not altered by exposure to a red heat, but by heating to whiteness it assumes the metallic appearance of the ordinary or hammered metal, and no longer soils the fingers; in its finely divided state it absorbs and condenses gases within its pores, with the evolution of considerable heat, and if introduced into a mixture of oxygen and hydrogen it gives rise to their immediate combination; it likewise promotes in a remarkable manner the oxidation of alcohol or wood-spirit, when moistened with these and exposed to the atmosphere, producing therefrom acetic and formic acids respectively. Platinum in this form, as also *spongy* platinum, is rapidly attacked when somewhat strongly heated with sulphur, while the hammered metal is but very slowly attacked by the same treatment.

Platinum-black is obtained as a black powder when alcohol is cautiously added to a solution of platinous chloride ($PtCl_2$) in a hot solution of potash, the reaction being attended with a copious and violent liberation of carbonic anhydride (CO_2); the black precipitate so obtained requires washing with alcohol, afterwards with hydrochloric acid and potash, and lastly with water. This body is also obtained when a solution of platinic chloride ($PtCl_4$) is boiled with sodic carbonate and sugar; or by precipitation with zinc from a solution of platinic chloride containing an excess of hydrochloric acid.

200. Spongy Platinum.—This is the name applied to the spongy, slightly coherent form of metallic platinum, obtained by heating to redness the yellow double chloride of platinum and ammonium ($2NH_4Cl, PtCl_4$), precipitated on the addition of ammonic chloride (NH_4Cl) to a solution of platinic chloride; which precipitate, on the application of heat, gives off chlorine and ammonic chloride, and there remains a residue of *spongy platinum.* By the application of pressure to this substance when at a full red heat, its particles may be *welded* together, when it assumes the form and appearance of commercial platinum. Like the other forms of platinum, it is capable of inducing chemical combination in the mixtures of

certain combustible gases; at a strong red heat it unites with sulphur and phosphorus, and may also be alloyed with most other metals on the application of heat.

201. Occurrence of Platinum.—Patinum is a comparatively rare metal, which, like gold, always occurs in the *native* state, and it very frequently accompanies the latter in alluvial sands, gravels, and debris of the earliest geological formations, but, unlike gold, it does not frequently occur in large masses or nuggets, though such have been found weighing upwards of twenty-two pounds each; the more general form of its occurrence is, however, as rounded or flattened grains of a light steel-grey colour and metallic lustre, occurring, as already noted, in alluvial deposits, detritus, and auriferous sands, accompanied with magnetic iron ore, corundum, and occasionally chrome iron ore, zircon, spinel, serpentine, and augitic debris; when after the separation, by careful washing operations, of much of the sandy, earthy, and lighter portions of the ore, there remains a residue consisting of grains of platinum, along with gold, magnetic iron ore, corundum, and an exceedingly heavy alloy of osmium and iridium, and from this residue the gold, if present in considerable proportions, is separated by amalgamation, while the magnetic iron ore may be removed by the magnet. The *native* metal is never pure, containing only from 70 to 85 per cent. of platinum, the remainder consisting of *iron*, forming occasionally as much as 13 per cent. of the ore, *palladium* to the extent of from $\frac{1}{2}$ to 1 per cent., with *iridium, rhodium, osmium, ruthenium*, and *copper*, with frequently *gold* and *silver*, and occasionally *lead* and *manganese*. The chief localities of the occurrence of this metal are Russia, in the districts of the Urals, Brazil, Mexico, Peru, Borneo, California, Oregon, St. Domingo, Siberia, Australia, etc., and also in small quantities in certain copper ores occurring in the neighbourhood of the Alps.

202. Extraction.—The *wet methods* of extracting platinum were, until within a few years ago, the only ones adopted for the separation of this metal from the other metals, osmium, iridium, palladium, etc., with which it is always alloyed in nature, the very refractory nature of platinum rendering it impossible to effect the separation and refining of the metal

by methods of fusion, until Deville and Debray succeeded, by means of the oxyhydrogen flame, in melting the metal on a bed of lime, in quantities of twenty pounds and upwards.

In the separation of platinum by the **"wet method,"** the ore, after careful and complicated washings, and separation of the gold by amalgamation, is first treated with nitric acid, by which silver, copper, iron, and lead, are extracted; the residue, after washing with water, is digested at a gentle heat with hydrochloric acid, to which is added at intervals small quantities of nitric acid, the digestion being continued so long as the acid dissolves anything further, when the liquid is evaporated to the consistency of syrup, to expel the excess of nitric acid, then diluted with water and drawn off, after which the residue is again treated in the same manner with fresh acid, the operation being repeated so long as anything is extracted by the acids; the red solution thus obtained contains the chlorides of platinum, palladium, rhodium, and some iridium, while the residue in the retort consists of grains and plates of an alloy of osmium and iridium, along with quartz, corundum, and other foreign insoluble matters occurring with the ore.

To separate the palladium the solution is boiled, by which the tetrachloride of palladium is reduced to the state of dichloride, when, on the addition of potassium chloride, the sparingly soluble yellow double chloride of platinum and potassium is precipitated; or in the presence of iridium, the precipitate is red in colour and contains in addition the double chlorides of iridium and potassium. The separation of the last portions of the iridium is attended with considerable difficulty; but for this purpose the precipitated chlorides, after well washing, are ignited with twice their weight of potassic carbonate, by which the platinum is reduced, and the iridium converted into trioxide, when, after dissolving out the potassium salts, the residue is again treated with aqua regia, by which the platinum is dissolved, while the oxide of iridium is, to a large extent, left in the residue; and to complete the elimination of the iridium, it may be necessary to repeat the precipitation with potassium chloride, and ignition with potassic carbonate, several times, after which

ammonic chloride (sal-ammoniac) is added to the solution of platinic chloride thus obtained, when the double chloride of platinum and ammonium ($2\,NH_4Cl,\ PtCl_4$) so precipitated is washed, dried, and ignited in a black lead or plumbago crucible, when a black powder remains, which is platinum in its *spongy* form.

If the presence of a small amount of iridium be not of importance for the purpose to which the metal is to be applied, then the two metals are precipitated together in the first instance after the solution of the ore in nitro-muriatic acid, by ammonic chloride instead of by potassium chloride, and the precipitate so obtained at once ignited for *spongy platinum.*

For application in the requirements of the arts and manu-factures, the metal still requires conversion into a coherent and workable form, for which purpose the particles of the fine powder thus obtained require to be *welded* together for the production of a solid malleable metal, an operation until recently accomplished by subjecting it to the combined action of heat and pressure in the following manner, as introduced by Dr. Wollaston. The spongy platinum being reduced to as fine and uniform a powder as possible (by gently rubbing it between the hands, and afterwards in a wooden mortar), is sifted through a fine lawn sieve, and, after separation of the coarser particles, it is made into a thin uniform paste or mud with water, and introduced into a conical brass cylinder, about 6·75 inches in height, by 1·12 inch in diameter at the top, and 1·23 inch at the bottom, to the bottom end of which is fitted a steel plug, entering the cylinder for a length of about ·25 inch, and covered over with bibulous paper to facilitate the drawing off of water from the cylinder. The cylinder, well greased internally, is filled with water, and introduced into another vessel also filled with water, where the cylinder is completely filled with the platinum paste, the latter displacing the water in the cylinder; the surface of the paste is covered with blotting paper, succeeded by a woollen cloth, and after pressing out a portion of the water, by the pressure of the hand applied to a wooden plug, a copper plate is placed on the surface, and the cylinder so prepared is introduced into a powerful horizontal lever press, where it

is subjected to considerable pressure, whereby the water is to a very large extent expelled, and the spongy metal is compressed into a coherent, somewhat porous cake, which is then extracted by withdrawing the plug from the bottom of the cylinder.

The cake of metal is now heated upon a charcoal fire, for the expulsion of grease and any water it may still retain, from whence it is transferred to a wind furnace, where the cake is placed upon its edge and heated during twenty or thirty minutes to an intense heat, when, after allowing the temperature to fall slightly, it is removed, while still at a white heat, and further condensed by careful hammering upon its ends, and never upon the sides, otherwise the metal will crack in the operation; after this treatment the particles are found to be *welded* together, and the metal is obtained in the malleable and ductile form required for use in the arts. The ferruginous scale with which the metal is often covered, after the last manipulation, is cleaned off by coating it over with a mixture of borax and cream of tartar or potassic carbonate, then it is covered over with an earthen pot, and inserted on a platinum tray into an air furnace, when, after the metal has attained a red heat, it is withdrawn and at once introduced into dilute .sulphuric acid, by which its surface is perfectly cleaned.

To *refine* the metal, increase its density, and free from the pores, etc., which the metal, as prepared by the above method of Wollaston, is liable to contain, Deville and Debray have introduced a furnace (fig. 58) in which the metal may be melted and poured out from the lip *a* into moulds for the casting of ingots; the furnace also effecting the removal of any small quantities of osmium and silicon which the platinum may have retained, the former as an oxide, which is volatilized, while the latter forms a fusible calcic silicate, which is absorbed by the lime of the walls of the furnace, and any traces of palladium, lead, silver, or gold that might have remained with the platinum are also removed, probably by volatilization, during this operation. The furnace (fig. 58) is an oxyhydrogen furnace, formed of two blocks of lime *d, e*, placed together, as shown, and braced around with bands or wires of iron, to prevent the breaking down of the furnace

by the cracking of the lime. The metal to be melted is placed on the hollow cavity of the lower block d, and one or two apertures, according to the capacity of the furnace, are made in the upper block for the introduction of the jet or jets of the oxyhydrogen blowpipe. The pipe b supplies hydrogen or coal gas, while c is connected with a gas-holder containing oxygen, which it introduces, at a pressure of from 16 to 20 inches of water, along the pipe shown, into the centre of the hydrogen flame, the hydrogen being ignited before the oxygen is turned on, and in this manner a temperature can be obtained sufficient to melt platinum readily, from 40 to 60 minutes sufficing to melt and refine from 20 to 30 lbs. of platinum, which is then cast by pouring the metal from the lip a into moulds of gas coke, or iron moulds lined with platinum.
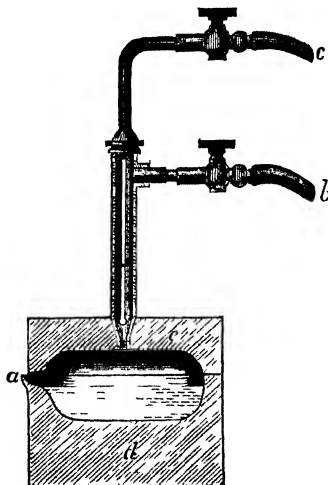
Fig. 58.—LIME FURNACE FOR MELTING AND REFINING PLATINUM.

To supersede the method of welding together the particles of spongy platinum by the method of Dr. Wollaston, and to obtain a more dense and uniform metal than that process affords, Messrs. Deville and Debray also introduced the furnace

illustrated in fig. 59, which is simply for melting platinum for the purpose of casting into ingots, without exercising the refining action possessed by the last described or lime furnace. This apparatus consists of a crucible of gas-coke, containing the spongy platinum to be melted; this is enclosed within another crucible of lime, fitted with a conical cover, also of lime, the compound crucible so formed resting on a small stand or block of lime, while the furnace proper consists of three blocks of lime, one of which forms the base,
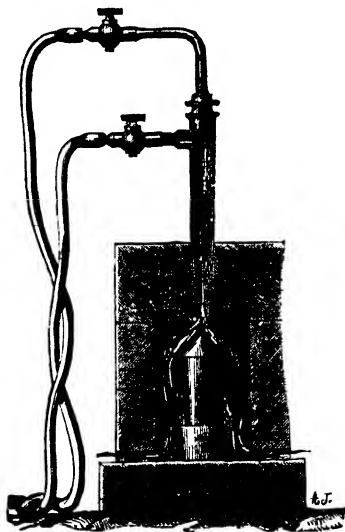
Fig. 59.—FURNACE FOR MELTING PLATINUM.

while the second resting upon it is bored to the form of a cylinder, and measures about $4\frac{1}{2}$ inches in height, and has four apertures around its base for the escape of the flame and products of combustion, while the top of the furnace consists of a somewhat thicker slab of lime, perforated with a conical opening for the introduction of the oxyhydrogen jet, in the manner described for fig 58, the several blocks of lime being each strengthened and held together by iron

wires, to prevent their breaking down under the influence of the intense heat. In this furnace, ingots of commercial platinum weighing upwards of 2 cwt. have been melted.

Other *wet methods* have been proposed by W. von Schnieder, M. Döbereiner, etc., for the separation of platinum from osmium, iridium, and other metals of the platinum group contained in the solution of their mixed chlorides, obtained by the treatment of the platinum ore with *aqua regia*. W. von Schnieder proposes to boil the solution with an excess of caustic soda, free from potash, whereby the several metals, with the exception of platinum, are converted into lower chlorides, not precipitable by ammonic chloride, while the platinic chloride ($PtCl_4$) is scarcely affected by the treatment, and may be precipitated by the addition of ammonic chloride, and obtained in the form of spongy platinum, in the manner previously described. A like effect, but effecting the separation less completely, is produced by treatment with calcium hydrate in lieu of caustic soda, and this constitutes Döbereiner's method of purifying platinum.

Messrs. Deville and Debray have introduced a " dry method" for the extraction of platinum from its ores, by which a nearly pure, very malleable and ductile metal is obtained, though not so pure as that prepared by the "wet process." In the extraction of platinum by the "dry method," an alloy of lead and platinum, or a platiniferous lead, is first prepared, from which alloy the lead is largely separated by the ordinary methods of cupellation in a cupel of bone ash;* but in this case the cupellation requires completion on the bed of the oxyhydrogen furnace (fig. 58), since, as the lead is oxydized and removed, the alloy becomes more and more infusible, and the high temperature produced in this furnace is necessary to melt it. The alloy of platinum and lead is prepared by introducing some 2 cwt. of platinum ore (previously freed as completely as possible from earthy matter, etc., by repeated washing), along with half of its weight of galena (PbS), into a small reverberatory furnace, of which the bed is hollowed out, and formed of fire-brick lined with clay, the charge being introduced in small quan-

* For a description of the process of cupellation, see the Chapter on Lead and Silver in Vol. II.

tities at a time, on to the red-hot bed of the furnace, thorough mixture being maintained by repeatedly stirring the mixture with iron bars, whereby a metalliferous matt results, when a quantity of difficultly fusible glass is added, which forms a flux or covering to the surface of the matt, and an amount of litharge (PbO), equal to the weight of the galena (PbS), is gradually added, when the oxide and sulphide of lead react upon each other, whereby sulphurous anhydride is evolved, and metallic lead is separated, which alloys with the platinum without taking up the osmium and iridium, the two latter forming a heavy osmium-iridium alloy, which gradually subsides on allowing the bath to remain undisturbed, forming a layer on the bottom of the furnace, above which floats the fluid alloy of platinum and lead, which, after allowing to rest some time for the more perfect separation of the osmium-iridium alloy, the platiniferous lead is ladled out and cast into ingots, while the residue remaining on the bottom is again added to a subsequent charge.

The platiniferous lead thus obtained is now subjected to cupellation upon a test or cupel, in the ordinary manner of cupellation, whereby the lead is removed as litharge, which melts and is absorbed by, and passes through the substance of the test, while the platinum is left on the cupel as a crude spongy mass, retaining small portions of lead, osmium, iridium, and rhodium, which is transferred for *refining* and *fusion* on to the lime hearth of the oxyhydrogen lime furnace represented in fig. 58. After which treatment the metal still retains traces of iridium and rhodium, which have the effect of rendering the metal a little harder and less fusible, or better adapted to most of its applications in the arts.

203. Alloys of Platinum.—Under the influence of heat, platinum alloys with most of the other metals, producing bodies which are usually considerably more fusible than platinum itself, and for this reason the melting of metallic bodies in platinum vessels is to be carefully avoided. Thus, on the application of heat, platinum unites with *antimony* or *arsenic*, the union being attended with incandescence and the production of brittle and readily fusible alloys; with *bismuth*, also, union takes place readily, but without incandescence, and the alloy is again brittle and readily fusible:

but if these alloys be heated in the air continuously for some time, almost the whole of the antimony, arsenic, or bismuth are oxidized, and a residue of platinum remains.

Platinum alloys with *iron* and *steel,* producing bodies more or less difficultly fusible, according to the proportion of platinum present; with equal weights of the two metals the alloy requires the heat of the oxyhydrogen blowpipe for its fusion, whilst with but 1 per cent. of platinum a steel may be produced, which is readily melted in the ordinary furnaces (see page 54).

Gold and platinum alloy together, with the formation of alloys which approach more or less to the colour of gold, as the proportion of the latter is increased, and with the increase in the amount of gold, the melting point of the alloy is also lowered.

Lead and platinum combine very easily with the production, if the proportion of lead be considerable, of readily fusible alloys, the fusibility decreasing with an increase in the amount of platinum present.

Platinum and *silver* alloy well together, small proportions of the former rendering silver harder and less white. The silver may be extracted from this alloy by boiling sulphuric acid; while nitric acid, if the silver be present in considerable quantity, dissolves both metals.

The most important alloys of platinum, for the purposes of the arts and manufactures, are those with the rarer metals *iridium* and *rhodium,* with which platinum always occurs associated. and the perfect separation of which is attended with considerable trouble and expense, while for many purposes the alloy of these three metals is better adapted than is the pure metal, since the alloy is harder, less fusible, and less easily attacked by chemical reagents. In the preparation of this alloy it is only necessary to fuse the ore along with 4 or 5 per cent. of lime in the oxyhydrogen flame, for which purpose a bed of lime is required (fig. 58) to hold the fused alloy, and to absorb the fusible slags produced by the oxidation of the *copper* and *iron* present in the ore of platinum, while the *palladium* and *osmium* originally present are volatilized at the high temperature employed.

An *amalgam* of platinum of a silvery appearance, may be

obtained by triturating the spongy metal with mercury in a warm mortar, the union being promoted by moistening the mixture with water acidified with acetic acid, and from this amalgam the mercury is expelled on the application of heat, and a residue of platinum is deposited. The hammered or compact metal does not amalgamate with mercury. The amalgam containing 12 per cent. of platinum, is metallic in appearance, and possesses a soft greasy feel, the solidity of the substance increasing with the proportion of platinum, until with from 40 per cent. to 45 per cent. of platinum, the amalgam assumes the form of a dark grey solid.

ADDENDA.

Metallurgical Terms.—The body formed by the union or combination of two or more metals with each other is termed an "*alloy*," and if one of the constituent metals be mercury, the resulting substance is known as an "*amalgam.*"

Liquation or *eliquation* is the name applied to the process by which bodies having different melting points, or which solidify at different temperatures, are separated from one another by subjecting the mixture to a carefully regulated temperature; examples of such are afforded in the metallurgy of bismuth, antimony, etc., and in the separation of an argentiferous lead from an alloy containing lead, silver, and copper; the alloy of lead and copper requiring a much higher temperature for its fusion than does the argentiferous lead.

Action of Nitric Acid on Alloys.—The metals most likely to occur in alloys are two or more of the following, viz. :—*antimony, arsenic, aluminum, bismuth, copper, cobalt, gold, iron, lead, mercury, nickel, platinum, silver, tin,* and *zinc;* and frequently certain non-metallic elements, as *sulphur* and *phosphorus,* also occur in bodies classed as metallic alloys; of this class is the substance known as phosphor-bronze, described in Vol. II.

If *no reaction* occurs on treatment with nitric acid, there is a probable absence of all the above metals, except, possibly, *gold* and *platinum.*

If a *reaction* occurs on treatment with nitric acid, with the evolution of nitrous fumes, it indicates the presence of one or more of the following, viz.:—*arsenic, antimony, aluminum, bismuth, copper, cobalt, iron, lead, mercury, nickel, silver, tin,* or *zinc,* all of which, with the exception of *antimony* and *tin,* are dissolved by the acid, while these two are deposited as a white residue, consisting of the *oxides* of *antimony* and *tin* respectively; accordingly, if a reaction ensues, the solution will then contain the above metals which are soluble in the acid, and in the presence of *large quantities* of silver might also contain *platinum* in addition; and any residue after the treatment, if it be *white,* arises from *antimony* or *tin,* with only small proportions of *gold* and *platinum,* if these be present, and may contain *silver* or *lead* in small proportions; while a *black* powder or *metallic* residue indicates *gold* or

platinum, with possibly small proportions of *antimony, tin, silver,* or *lead.*

Coke Ovens.—In the coke burning districts of the North of England, the coke ovens described on page 29 are usually built in rows of from 5 to 8 together, forming one range of ovens, each of which has the form and dimensions already described; or, instead of being circular, as described, may measure about 10 feet in width by 12 feet in length, and have a total height of some 7 feet 6 inches or 8 feet; the roof or arch, formed of brickwork, about 1 foot 6 inches in thickness, springing from the side walls, and having an opening in its summit for the escape of volatile matters during the coking and as an opening for the introduction of the charge in the manner already described.

Speigeleisen.—This is a manganiferous pig-iron, often possessing well-marked physical qualities; its fracture especially usually presenting large cleavage planes, though these are not essential to the existence of good speigeleisen. Its essential constituents are from 4 to 5 per cent. of carbon, which exists almost wholly in the combined state, with upwards of 6 per cent. of manganese, commercial varieties usually containing from 8 to 12 per cent. of this metal, while special samples will contain as much as 20 or 30 per cent. of this element. If the speigel contain less than about 6 per cent. of manganese, it is generally considered to be inapplicable for the purposes of the steel manufacture, and more especially for use in the Bessemer process.

ANALYSES OF SPEIGELEISEN.

Locality.	Germany.	England.	Germany.
Graphite, ...	0·27	0·293	{ 5·04
Combined carbon,..........	4·02	3·441	
Silicon, ...	0·48	0·215	0·41
Sulphur, ...	0·05	0·064	0·08
Phosphorus, ...	0·26	0·088	...
Manganese, ...	10·25	8·958	7·57
Copper,.......................	Trace.	0·012	0·16
Iron, ...	84·67	86·917	86·74
	100·00	99·988	100·00

Until a very recent date this variety of pig-iron was produced in comparatively few localities, it being considered that its manufacture could only be successful where certain *spathic ores, brown iron ores* formed by their decomposition, or the *Franklinite* of New Jersey, U.S., were the subject of the smelting operation; *i.e.,* its manufacture depended upon the supply of an ore containing iron and *manganese* in considerable quantity, while at the same time being practically free from sulphur and phosphorus. The chief European localities in which spathic iron ores occur are Styria, Lölling, and

Carinthia in Austria ; Siegen and Musen in Rhenish Prussia ; Hungary, Hanover, Russia, and in the Brendon Hills of England, the ore of the last named being worked by the Ebbw Vale Iron Company, who, until the past two or three years, enjoyed a monoply in the manufacture of this article in England ; but more recently ores capable of yielding speigeleisen, have been imported from Spain, and smelted at the Atlas Works, Sheffield. This article is now produced in the furnaces of Messrs Bolcklow, Vaughan, and Company, the Landore Siemens Steel Company, etc. The *magnetites* of Sweden, although practically free from sulphur and phosphorus, as indicated in the accompanying analyses of Professor Akerman, and some of which contain considerable proportions of manganese, are not sufficiently rich in the latter to yield speigeleisen in the blast furnace ; yet, latterly, certain Swedish ores, as those of Schisshyttan, which are said to yield from 13 to 20 per cent. of manganese, have been mixed with magnetic iron ores for the production of speigeleisen.

ANALYSES OF SWEDISH IRON ORES.

Locality.	Persberg (uncalcined).	Danne- mora (calcined).	Stora Bispberg (calcined).	Norberg (uncalcined).	Grasberg (calcined).
Ferric oxide (Fe_2O_3), ⎧	...	...	68·8	...	61·2
Magnetic oxide (Fe_3O_4), ⎨	66·7	74·9	21·7	64·00	
Manganous oxide (MnO),	2·06	1·53	0·16	0·10	0·3
Phosphorus, . . .	0·022	0·008	0·008	0·014	0·043
Sulphur, . . .	...	0·04	...	0·003	0·02
Iron, ...	48·3%	54·3%	63·8%	46·3%	43·7%

For the production of speigeleisen from spathic ores in the Siegen district of Rhenish Prussia, the ore is carefully picked to free from copper pyrites, after which it is roasted or calcined in kilns, which are charged with alternate layers of ore and coke, cinders or charcoal refuse, the kilns being fired from the bottom, and kept in continuous action by raking out the ore from the bottom of the kiln as soon as the calcination is completed in that zone, and continually supplying the place of the materials so removed by fresh ore and fuel added at the top of the kiln. The calcined ore is smelted in the blast furnace with the addition of a large proportion of lime (usually burnt), and only small quantities of clay-slate, whereby *basic* slags are produced, and the reduction of the silicon in the furnace greatly impeded, while coke or charcoal is the fuel employed. If the slags be too rich in silica, the latter combines with the manganese, which thereby largely escapes reduction, and grey or mottled iron only is produced in the furnace ; and, again, if the temperature be too low, and the

burden too heavy, white iron is produced. It is thus manifest that, with a suitable ore, the production of this variety of pig-iron requires considerable care, and is not even then perfectly under the control of the furnace manager, slight fluctuations in the temperature and pressure of the blast changing the make or yield from speigeleisen to grey, mottled, or white iron.

Low Moor and Bowling Iron.—The ore employed at Bowling and Low Moor for the production of the best iron of the works of this district, is a dark brown argillaceous ironstone occurring in the coal measures of the locality, yielding, in its raw state, about 32 per cent. * or after calcination, 42 per cent. of iron. This ore is smelted with coke from what is known as the "*better bed coal*" of the district, the proportion of about 4 tons of the raw ore, or 2 tons 7 cwt. of the calcined ore, with 18½ cwts. of limestone obtained from the neighbourhood of Skipton, and 2¼ tons of coke from the above coal, being required for the production of 1 ton of pig-iron. For conversion into plates, etc., the pig-iron is conveyed at once to the refineries, and the yield of about 2 tons of *refined metal* obtained from each finery is run into a mould cooled by water, some 12 feet long and 4 feet wide; the *plate metal* so obtained is then puddled in charges of about 3 cwt., each furnace working off ten charges per day, and the puddled ball or bloom is shingled under the hammer for the expulsion of slag, scoria, etc., and formed into slabs, known as "stampings" or "noblins." The *stampings* are broken up, piled, reheated, and hammered into blooms or billets, which are then transferred to the mill, and, after again reheating, are rolled into bars, angle-irons, or other forms; while the *noblins* are subjected to a similar treatment to the stampings, except that they are formed into blooms suitable for rolling in the plate-mill for the production of plates, etc.

Slag from Bessemer Process.—The slag remaining in the Bessemer converter, after teeming the metal into the ladle, is a heterogeneous, porphyritic-looking, siliceous mixture, consisting of a fused portion or flux, forming the true slag, enveloping and cementing together large quantities of apparently unfused quartzose matters derived from the sides of the converter, etc. The composition of this slag or residue is accordingly exceedingly various, from the varying quantities of ganister, etc., detached from the lining of the converter in different blows. The following is one analysis of this siliceous mixture or slag :—

Ferrous oxide,	=	20·65
Manganous oxide,	=	2·96
Lime,	=	1·04
Alumina,	=	2·43
Silica,	=	72·25
Phosphoric acid,	=	Trace
Sulphuric acid,	=	0·86
Magnesia,	=	0·13
		100·32

* Proceedings of British Association, 1873.

Analyses of Steel Rails.—The following are analyses of two specimens of steel rails, manufactured by the Bessemer and the Siemens-Martin process respectively, indicating the temper, etc., of the steel used for this purpose:—

	Bessemer Rails.	Rails made by the Siemens-Martin Process.
Carbon, ...	·352	·370
Sulphur, ...	·055	·042
Silicon, ...	·053	·040
Phosphorus,...........	·061	·033
Manganese, ...	·384	·342
Copper,.................	Trace.	·008
Iron, ...	99·095	99·165
	100·000	100·000

Soft or Mild Centred Steel. — For certain purposes, as for the manufacture of taps, etc., where it is desired to make an article of a material that, while it may be hardened at the surface or working part, will yet retain the toughness due to the metal in its soft state, a variety of steel has been introduced, known as *mild centred steel*, in which the surface of the metal is much more highly carburized than the central part or core of the ingot or bar. In the manufacture of this class of steel, the ingots are cast of very mild steel in the manner already described; the ingots are then cogged (hammered) down, and afterwards introduced for conversion into the converting furnace (fig. 40, page 157), and exposed to the action of carbon, after the manner of ordinary bars in the converting process, by which means the exterior of the ingot becomes carburized to a depth determined by the duration of the process, while the centre retains its original softness; and after again hammering or rolling to the sizes required, the steel is ready for use.

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